REPORT

RELATIVE TO

WATER SUPPLY NEEDS

AND

RESOURCES OF THE COMMONWEALTH

HOUSE BILL 1550

JANUARY, 1922

HOUSE No. 1550

The Commonwealth of Massachusetts

REPORT OF THE JOINT BOARD

CONSISTING OF THE

STATE DEPARTMENT OF PUBLIC HEALTH

AND THE

METROPOLITAN DISTRICT COMMISSION

RELATIVE TO

WATER SUPPLY NEEDS AND RESOURCES OF THE COMMONWEALTH

UNDER THE PROVISIONS OF CHAPTER 49 OF THE RESOLVES OF THE YEAR 1919

JANUARY, 1922

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Resolved, That the state department of health and the metropolitan water and sewerage board, acting jointly, shall forthwith proceed to investigate the water supply needs of the inhabitants of the commonwealth, including all questions relating to the quantity of water to be obtained from available sources, its quality, the best methods of protecting the purity of the water, the construction, operation and maintenance of works for storing, conveying and purifying the water, the cost of the same, the damages to property, and all matters pertaining to the subject. The said board shall also consider and report whether any of the great ponds now used as sources of water supply might better be devoted to purposes of public recreation, and shall determine the extent to which boating, fishing or other use of any such sources may properly be authorized. The said board shall have power to employ such engineering and other assistance and to incur such expenses as may be necessary for carrying out the provisions of this resolve, and shall report fully with plans and estimates to the general court on or before the first Wednesday in January in the year nineteen hundred and twenty-one, including in its report drafts of any legislation recommended by it. Before incurring any expense the board shall, from time to time, estimate the amount required therefor, and shall submit the same to the governor and council for their approval, and no expense shall be incurred beyond the amount so estimated and approved. [*Approved June 24, 1919.*

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RESOLVE RELATIVE TO THE INVESTIGATION BY THE DEPARTMENT OF PUBLIC HEALTH AND THE METROPOLITAN DISTRICT COMMISSION RELATIVE TO WATER SUPPLY NEEDS AND RESOURCES AND TO THE USE OF GREAT PONDS.

Resolved, That the time within which the department of public health and the metropolitan district commission shall present to the general court the report required by chapter forty-nine of the resolves of nineteen hundred and nineteen, relative to the water supply needs and resources of the commonwealth and to the use of great ponds, is hereby extended to the second Wednesday in January in the year nineteen hundred and twenty-two, and shall include therein a report of the availability, as sources of water supply, of water obtained through systems of filtration. In making said report a system of filtering the waters of the Merrimack river and other streams, as well as the employment of artesian wells, shall be considered as among the available sources of water supply to be reported upon. [*Approved May 9, 1921.*

REPORT OF THE STATE DEPARTMENT OF PUBLIC HEALTH AND THE METROPOLITAN DISTRICT COMMISSION UPON THE WATER SUPPLY NEEDS AND RESOURCES OF THE COMMONWEALTH.

January 28, 1922.

To the General Court of Massachusetts.

In 1919 the Legislature, by chapter 49 of the Resolves of that year, committed to the State Department of Health and the Metropolitan Water and Sewerage Board, acting jointly, the task of investigating the water supply needs of the inhabitants of the Commonwealth, including all questions relating to the quantity of water to be obtained from available sources, its quality, the best methods of protecting the purity of the water, the construction, operation and maintenance of works for storing, conveying and purifying the water, the cost of the same, the damages to property, and all matters pertaining to the subject. The Joint Board was further ordered to consider whether any of the great ponds now used as sources of water supply might better be devoted to purposes of public recreation, and to determine the extent to which boating, fishing or other use of any such sources may properly be authorized. In 1921 the Legislature, by chapter 42 of its resolves, extended the time for making the report, and amplified the investigation so as to include "the availability, as sources of water supply, of water obtained through systems of filtration . . . a system of filtering the waters of the Merrimack river and other streams, as well as the employment of artesian wells . . ." We have conducted these investigations and now submit the following report.

The resolve of 1919, under which the investigation has been conducted, was so broad that it was necessary to place a limit on the extent of the studies made, corresponding to what could be accomplished within the appropriation available.

Organization of the Joint Board, as we shall for convenience call ourselves, was effected July 3, 1919. Dr. Henry P. Walcott, then chairman of the Metropolitan Water and Sewerage Board, was chosen as chairman, Mr. X. H. Goodnough as secretary and engineer, and Mr. Frederic P. Stearns as consulting engineer. A few months later several important changes occurred which affected this organization. Dr. Walcott, who had given eminent service to the Commonwealth for more than a generation, resigned in November, and Mr. Stearns died on December 1. On December 1, 1919, the newly constituted Metropolitan District Commission assumed the functions of the Metropolitan Water and Sewerage Board. Dr. Eugene R. Kelley, Commissioner of Public Health, has served as chairman since the resignation of Dr. H. P. Walcott. Mr. X. H. Goodnough has been the chief engineer of the Joint Board in active charge of the investigation; his principal assistant has been Mr. Bertram Brewer. Mr. J. Waldo Smith, eminent in his profession and well known for his work as chief engineer of the New York Board of Water Supply, in connection with the Catskill Water Supply of that city, has been the consulting engineer. Dr. Henry P. Walcott very graciously consented to act as an adviser to the Joint Board. Advice has been received from Prof. W. O. Crosby and Prof. Charles P. Berkey on matters of geology, and from Mr. Harry W. Clark on water filtration. Mr. Charles T. Main has been consulted on matters connected with water power, and Mr. Ralph A. Stewart on special legal questions.

Because of unexpected delays, the Joint Board was unable to report in January, 1921, and asked the Legislature for an extension of time until the second Wednesday in January, 1922, which request was granted.

The chief engineer has prepared an able report including computations and estimates of the water supply needs of the various communities, studies of water resources, maps, general plans for certain projects, financial statements, and other data pertinent to the investigation, which is herewith submitted, together with the report of the consulting engineer. Many other statistical data, computations, maps, plans, and the like, of great permanent value to the Commonwealth, omitted from the report because of the expense of printing, are on file in the engineering office of the Department of Public Health. This report contains a summary of the recommendations of the Joint Board, followed by a brief discussion of the more important topics.

Summary of Recommendations.

1. Definite arrangements should at once be made for securing an additional supply of water from the Ware River for the joint use of the Metropolitan Water District and the city of Worcester.

2. A tunnel about 13 feet in diameter and about 12 miles long should be constructed from the Wachusett Reservoir westward to Coldbrook on the Ware River at an estimated cost of about $12,000,000.

3. This tunnel should be used to divert the flood flows of the Ware River to the Wachusett Reservoir, securing an additional supply of water of about 33,000,000 gallons per day, in such a way as to interfere as little as possible with the mills on the lower Ware River.

4. Provision should be made for pumping water from this tunnel into a stream which flows to Pine Hill Reservoir, now being constructed by the city of Worcester, or from the Wachusett Reservoir into the Worcester distributing system, as may hereafter be determined.

5. The Swift River project, involving the construction of a great reservoir near Enfield, and connecting it with the Wachusett Reservoir by means of an extension of the tunnel to the Ware River, should be approved as the logical extension of the water supply system.

6. The construction work on the approved project should be progressively developed as required in order to insure at all times an adequate supply of water to the Metropolitan District and to Worcester.

7. Plans should be drawn for filtering the waters of the South Sudbury and Cochituate systems, now held as reserve supplies, keeping in mind the ultimate filtration of all of the metropolitan water supply.

8. The South Sudbury and Cochituate filters should be constructed when needed.

9. Efforts to prevent leakage and waste of water should be continued in order to conserve the present supply to the greatest possible extent.

10. For the same reason the local supplies of the communities within the 10-mile radius and adjacent thereto should be developed to their economical limit, using filtration if necessary, but keeping in mind the possibility of their ultimate abandonment.

11. The construction of the proposed works should be entrusted to the Metropolitan District Commission or to a special commission, as the Legislature may determine.

12. A Southeastern Water District should be created to enable the cities of Fall River, New Bedford and Taunton, and such other cities and towns as may desire to do so, to develop the Assawompsett and adjacent ponds as a common source of water supply.

13. Consideration should be given to the advisability of organizing a similar water district in Essex County for the purpose of developing the Ipswich River by the construction of one or more large storage reservoirs for the joint use of the cities and towns in that part of the State.

14. Consideration should be given to the advisability of organizing still another water supply district in Hampden County for the purpose of developing the Westfield River for water supply purposes.

General Considerations.

Massachusetts is a well-watered State. The rainfall is ordinarily ample and well distributed through the year, although here, as everywhere, there are periods of surplus and deficiency. The natural conditions for storing water in reservoirs or in the sand and gravel beneath the earth's surface are also good, so that it is not a difficult matter to convert the intermittent rainfall into a constant water supply. There is no reason why any city or town should have a deficient water supply if reasonable prudence is exercised in planning for the future. It is necessary, however, to make such plans and to have them carried out in anticipation of the relatively dry years which come at times no man can foretell. During the recent war period construction of public works of all kinds has necessarily been restricted. It is all the more necessary that at this time the cities of the Commonwealth should look well to the future of their supplies, and not take chances justified during the war.

While Massachusetts has abundant water resources, it must not be forgotten that there are other uses for water than those of public water supplies, — notably, uses for power development and for recreation. The streams afford necessary drainage opportunities and the catchment areas cannot be given over entirely to water collection. Obviously there are many conflicting interests which must be adjusted. We believe that they can be adjusted satisfactorily if the water needs and resources are considered in a broad way, in a spirit of fairness, and with recognition of the possibilities which lie in modern science. The use of water for domestic purposes should be recognized as having the highest claim, but cities must strive to restrict waste and utilize trustworthy methods of water purification in order that existing supplies be maintained as long as economical considerations warrant their retention. The need of using water power in order to save fuel must be recognized, as well as the advisability of using gravity water supplies where economical, in order to save the fuel required for pumping. Restrictions on watersheds, in order to safeguard the quality of the water, should be sufficient for safety. The importance of utilizing lakes and streams for such recreational purposes as boating and fishing and for the beautification of natural parks must be kept in mind, but the paramount necessity of protecting the quality of domestic water supplies against accidental infection by carriers of disease germs dangerous to the public health must be fully recognized. Nor must it be forgotten that there are certain interstate water relations which may sometime become of greater importance than is apparent to-day.

The Use of Flood Waters for Water Supply Purposes.

While domestic water supply is properly recognized as the most important use of a stream, the advantage of utilizing falling water for power is of great and growing importance. For many manufacturing purposes water is essential, and the use of a stream for furnishing process water and for diluting liquid wastes, even though partially purified, is an important one. When all, or nearly all, of the water of a stream is diverted for water supply, the stream is often left in a sorry condition. Even if fuel power be substituted for water power and ample compensation made for the required change, there are incidental and intangible damages to the Commonwealth which ought not to be overlooked. A stream cannot be reduced in size without injuring the riparian communities and retarding their growth.

In Massachusetts the streams have more or less regular periods of high and low flow. For several months the flow is larger than can be economically utilized, while for several months the streams are relatively dry. Both for water supply and power purposes uniformity is secured by building storage reservoirs. If the stream flows were the same year after year, it would be possible to build reservoirs of such capacity that practically all the water could be used and none wasted; but the flows are far from constant, hence it is not possible to build reservoirs to utilize all the water all the time. The economic size of the reservoir is dependent largely upon the value of the water.

The adverse effect of the diversion of water from the lower portions of a stream is limited chiefly to the periods of low stream flow, while in the spring the natural excess of water is of little benefit and often is definitely injurious.

Although the State of Massachusetts is well watered, the value of this natural resource is increasing and will continue to increase as time goes on. In planning for an increased supply of water for the Metropolitan District, the chief engineer has endeavored to work out a plan by which the flood flows will be utilized to a greater extent than has been customary in the past. To do this means the construction of reservoirs of larger size and greater cost. But by the storage of the spring flood waters, and by letting water out of the reservoir in proper amounts, it will be possible during dry weather to maintain the flows of the streams below the dams at their normal seasonal height. Hence the greater cost of the reservoirs will be to some extent offset by decreased damages to the downstream riparian owners who use the water for power and manufacturing purposes. This idea may be called that of "taking the flood flows" as compared with the practice of "taking the stream flow" heretofore common. It should enable the water supply resources of the State to be increased with a minimum of injury to the other users of water. We believe that the benefits of the plan are so obvious that the riparian owners ought to be willing to co-operate with the State in every possible way in making the plan a success. We believe that in general the mill owners want water, not money.

We hold that the communities in the central part of the State should not be called upon to sacrifice their summer rivers for the benefit of the Metropolitan District when it is possible to utilize the spring flood waters which would otherwise go to waste. It is this thought which underlies the projects for the utilization of the Ware River, and ultimately the Swift River.

General Policy of Filtration of Surface Water.

It has long been the policy in Massachusetts to secure water supplies from unpolluted sources whenever they could be obtained, and to use natural protective measures to safeguard their quality. These natural safeguards have their limits. As time goes on, as the populations on the watersheds increase, it will be necessary to adopt the policy of filtering surface water supplies. Disinfection is a cheaper method, but is less reliable and more distasteful. Massachusetts waters are ordinarily clear, but some of them have a noticeable brown color, caused by the natural brewing of harmless organic matter in swampy areas. When stored in reservoirs, microscopic organisms, collectively known as algæ and protozoa, develop erratically, and at certain seasons impart grassy, oily or fishy odors to the water. The fact that these substances are probably without effect on the health of persons drinking the water does not lessen the complaints of the average consumer. By filtration, supplemented by aeration and where necessary by chemical treatment, the surface water supplies of the State can be made not only safe but attractive in all respects and at all times. When the Wachusett Reservoir was built, about $2,000,000 was spent in removing the soil from the flooded area in order to prevent the growth of microscopic organisms. Undoubtedly this protective measure improved the quality of the water during the early years, but it did not wholly prevent the growth of organisms. New York City, when it constructed its Catskill supply, decided to depend upon filtration rather than soil removal, believing that money so spent would bring a better return from the investment. The filters have not yet been built. In planning the Swift River reservoir, the chief engineer has chosen to rely upon filtration rather than soil removal or chemical treatment. It may not be necessary to construct filters for this water in the near future, but we believe that the entire metropolitan supply must ultimately be filtered.

The time is not far distant when some of the local water supplies of the Boston metropolitan area must be either filtered or abandoned. We believe that in these cases the decision should be made on economic grounds. The possibility of obtaining satisfactory water by filtration should be recognized, but the advisability of continuing the use of supplies where the fuel costs of pumping and the cost of maintaining small filters with constant attendance are high must be considered and compared with the cost of obtaining a gravity supply from the common sources of the district.

There is a constant and increasing demand on the part of the people of the State to utilize for pleasure purposes the natural and artificial bodies of water used as public water supplies when they are located near centers of population. Where dependence is placed only upon the natural protection which is inherent in the storage of water, it is our opinion that the practice of bathing, fishing and boating should be absolutely prohibited in bodies of water used directly as sources of water supply, for the reason that the danger to the public health overbalances the collective benefits to the bathers and fishermen. Where the water supply is filtered by a filter which has constant attendance, boating and fishing may be allowed under suitable restrictions. In the case of bodies of water used indirectly as sources of water supply, boating and fishing should be permitted under proper regulations.

The following general principles should be considered as representing the Massachusetts policy for protecting the purity of her surface water supplies: (1) choice of unpolluted sources as far as practicable; (2) utilization of the natural agencies of purification to the greatest practicable extent; (3) prevention of pollution by land purchase and by the enforcement of sanitary rules and regulations; (4) filtration of water (*a*) when the population on the watershed is relatively large, (*b*) when it is desired to permit boating and fishing in the sources of supply, and (*c*) when the water is unsatisfactory in its appearance, taste or odor; (5) the choice of filtration and other purification methods to be governed by the nature of the supply, by cost considerations, and by the desire to produce a water hygienically safe, attractive in its appearance, tasteless and odorless, and without corrosive properties; (6) the combination of these various natural and artificial protective methods according to local conditions and economical considerations; (7) the storage of filtered water in covered basins as far as this is practicable.

Use of Great Ponds.

Without question the citizens of the Commonwealth have certain rights in the great ponds, but the people's representatives have wisely acted on the principle that the highest use of all the inland waters is that of supplying water for domestic needs, and have placed the oversight and care of these waters in the hands of the State Department of Public Health. As a necessary protection of the public health, rules and regulations have been made by this department, governing such matters as bathing, boating, fishing and ice-cutting, which in some cases have seemed unduly severe. The policy has been to make a distinction between ponds and reservoirs used directly, — namely, those from which the water flows into the pipes or aqueducts of the water works, and those used as auxiliaries to the direct supplies, applying restrictive measures to the former, but not the latter, or at least making the latter less severe.

In view of the fact that most of the water supplies taken from great ponds are used without filtration, we are of the opinion that the prohibition of bathing, boating and fishing, which are so likely to be accompanied by insanitary practices, is wise, and has been fully justified in cases where the raw water is used directly. We think, however, that there are water supplies of the State, such as Lake Cochituate, where, if the water were filtered under conditions assuring a regular and reliable degree of purification, boating and fishing under proper restrictions should be permitted in the interest of healthful recreation, which we regard as a public benefit.

It is our opinion, also, that even bathing in the great ponds would be an unappreciable menace to the public health if the water supply were not only adequately filtered but disinfected. Yet the idea of allowing people to bathe in water which is to be used for drinking offends the sensibilities of so many people that in our opinion bathing should be permitted under these conditions only with the consent of the communities using the water supply.

The Boston Metropolitan Water District.

The most important water supply problem of the State is that of the Boston Metropolitan District. According to the census of 1920 the population of Massachusetts was 3,852,356, one-half of which was within 15 miles of the State House. The cities and towns within the 10-mile radius, which now constitute the Metropolitan Water District, had a population of about 1,250,000. The growth of this region appears to be following the general law of population increase, — namely, an increasing annual increment but a lessening percentage rate. Between 1900 and 1910 the average rate of increase was 2.01 per cent per year; between 1910 and 1920, 1.59; and between 1915 and 1920, including the war period, 0.83 per cent. Estimates of future population are hazardous, for no one can foretell the future; yet it is necessary to make estimates in order to plan the size of water works required, and the safest way is to base them upon the past history of the district. The estimates made in 1895 were apparently somewhat too high, but with a longer record at our disposal, and with a better appreciation of the law of decreasing rate of growth, our present estimates ought to be more reliable. It is our opinion that there should be a water supply capable of supplying 1,500,000 people in 1930, 2,000,000 people in 1950, and 2,500,000 people in 1970.

We have given much study to the quantity of water which may reasonably be considered to fulfill the needs of the people of the district. The engineer's report contains the results of careful studies of the past water consumption. He has also brought together similar data for other American cities which are useful for comparison. The subject is one which has attracted the attention of engineers in all parts of the country, and from the data obtained certain general facts and tendencies appear to be well established.

The first is that a very large proportion of the water supplied to our American cities is wasted through careless use or lost through leaks. The proportion of water wasted and lost in different places varies all the way from one-quarter to three-quarters. Just what it is in the Metropolitan District is not definitely known. Perhaps a third is a reasonable estimate. It is certain, at any rate, that the average per capita consumption is lower in Boston than in any other American city of its size. The losses through leakage occur in part in the distribution mains, and are due to a multiplicity of small leaks and undiscovered breaks. The larger losses can be stopped if found, but they are difficult to find. Leaks from the plumbing fixtures within the houses are even more important, and metering has been found to be a partial check on these household leaks and wastes. It is not a permanent check, however, for the records of metered cities show that after a few years consumption again rises. Inspection of house fixtures and leakage surveys helps to keep down consumption, but even this is only partially successful. The same is true of increasing the selling price of water. While we believe strongly that waste should be restricted and thrift encouraged, we also hold that the public water supply should be ample for all reasonable needs, and that the actual use of water in the interest of improved health conditions should be encouraged.

The second fact is that there seems to be a tendency, one may say the world over, to an increased use of water in cities. Plumbing fixtures are much more numerous and require more lavish use of water than formerly, while water pressures tend to rise as buildings are higher. As cities grow in size, the per capita consumptions tend to increase practically without exception.

We will not attempt to follow the changes in the daily per capita water consumptions as they have varied from 91 gallons in 1895 to 128 in 1907, back to 87 gallons in 1915 and then up and down again. These facts are given by the chief engineer. But we have assumed that with waste cut down to a minimum the consumption will continue to rise at the rate of about a gallon per head per year. This has been the average rate of increase in Boston since 1850. In many cities, where there is a complete meterage, the increase is 2 gallons per year. Boston, however, has a smaller manufacturing use of water than most of such cities, hence we have used the more conservative figure.

The present water supply sources of the Metropolitan Water District — namely, the Wachusett and North Sudbury system, the South Sudbury system, and Lake Cochituate — are capable of delivering in a dry period about 155,000,000 gallons a day, possibly a little more. But of this only about 125,000,000 gallons is of first-class quality. The South Sudbury water is highly colored and is taken from a region where the population is large and increasing. The Cochituate water is taken from an even more populous region, and often has a bad taste and odor due to the presence of algæ and protozoa. Both the South Sudbury and the Cochituate supply are now regarded as reserves to be used only occasionally as emergencies require. They are important parts of the system, however, and can be made satisfactory for regular use by filtration.

In 1920 the average consumption of the Metropolitan District was 127,000,000 gallons a day, and if the rainfall had been as low as it is about once in twenty years the limit of the Wachusett–Sudbury supply would have been reached. As it happened, the rainfall was high and the reserve supply of low-grade water was not used to any extent.

The question which naturally arose was, why not filter the South Sudbury and Cochituate waters at once and make them fully available? That is indeed the cheapest and speediest method of increasing the available supply to 155,000,000 or more gallons a day in a dry period. It is our opinion that plans for the filtration of these supplies should be made at once in order that the work might be begun promptly in case of an unexpected increase in consumption or of a threatened drought, shown by a depletion of storage in the Wachusett Reservoir.

In making these plans consideration should be given to the probable ultimate filtration of all the water supply of the district. The reason for not recommending filtration of these sources at the present time is that we believe it to be more important to secure an additional supply of water for the district, still holding the South Sudbury and Cochituate sources in reserve.

If the Boston Metropolitan District continues to grow at the rate which prevailed just prior to the war, there will be an urgent need of more water by the year 1930 and perhaps before then. By that time, also, there is likely to be a demand for water from a number of cities and towns within the 10-mile radius, not now in the district but which have a right to call upon the district in case of emergency. This contingency cannot be left out of account. As it will require several years to construct the necessary works, we are of the opinion that the time has come to make definite arrangements for securing an additional supply.

There is another factor which needs consideration. The city of Worcester is also running short of water, and the limit of her present supply will be reached in about five or six years. Her present supply is contiguous to the Wachusett watershed; in fact, a part of her present supply is obtained by diverting the water of a stream within the Wachusett watershed. The city of Worcester has sought from the Legislature the right to divert more water from the Wachusett watershed, — namely, from the Quinepoxet River. In our opinion this diversion should not be allowed. We believe that it would be for the benefit of both the Metropolitan District and the city of Worcester to unite in securing a new source of supply, thus at once providing for the needs of Worcester and postponing for some years the filtration of the reserve supplies of the Metropolitan District.

Investigation of New Sources of Supply for the Metropolitan District.

In our search for the most practicable method of obtaining an additional supply of water, it was natural for us to turn back to the report which the Massachusetts State Board of Health made to the Legislature in 1895. They studied and rejected as unsuitable several possible sources of supply, — namely, the Charles River, the Shawsheen River, Assawompsett Pond, Lake Winnipesaukee, Sebago Lake, and the Merrimack River. We have re-examined these projects and have given especial attention to the possibilities of using certain of these supplies after filtration, as directed by the Legislature. In general, we find that the reasons for recommending against them in 1895 still hold good, and are even stronger now than then. The Assabet River was suggested in 1895 as the source from which the first additional supply should be taken, but the conditions have so changed meantime, due to the industrial development along the course of the stream, that it will not be wise to consider the use of this water as a possible regular source of supply. Yet inasmuch as the aqueduct from the Wachusett Reservoir passes through this watershed, the Assabet water could be readily diverted into it and used in case of a serious emergency. In fact, such an available emergency supply is an asset which should not be overlooked, as it will enable the district to follow safely a somewhat more conservative policy in regard to future extensions of the works than would otherwise be the case.

In 1895 chief reliance for the future supply of the district was placed upon the use of the Ware River, and after that, the Swift River. We believe that these ideas were sound, and our own recommendations are based upon them. Both of these sources of supply are sure to be needed. Two courses of action are open. One is to develop a supply from the Upper Ware River watershed, and later an independent supply from the Swift River, carrying both waters through separate tunnels to the Wachusett Reservoir. The other is to construct a single tunnel from the Wachusett Reservoir to the Swift River, crossing under the Ware River and so designed that it can be built in two installments, the first to take the Ware River supply, and the second to take both the Ware River and the Swift River. It is our opinion that the latter plan is much the better project, and it is the plan which we recommend.

In 1895 it was evidently the intention to utilize the Ware River water in the usual way by constructing a dam, impounding the water and taking the greater part of the stream flow. This would interfere with the use of water for power and other mill purposes below the dam, entail heavy damages and tend to prevent the development of the villages in the lower courses of the stream. During the last quarter century manufacturing along the lower Ware River has become more extensive, greater amounts of water are used for processes, and the liquid wastes have increased in amount. We have, therefore, endeavored to work out a plan of utilizing the Ware River water in such a way as to interfere as little as possible with the flow of the lower river. This can be done by diverting Ware River water to the Wachusett Reservoir and to the Pine Hill Reservoir of the Worcester supply at times when the Ware River flow is high, — say, above 1.2 cubic feet per second, or 800,000 gallons per day, for each square mile, — and at those times only. This will not interfere with the flow of the stream during those periods of the year when it is naturally low. It will, of course, take away some of the flood water, but it must be remembered that flood water is not worth as much to manufacturers as dry weather water, while it is worth just as much for water supply purposes if properly stored. The Wachusett Reservoir is of exceptionally large capacity, holding more than 50 per cent in excess of the average flow from its tributary watershed. It can, therefore, be used to store the flood waters of the Ware River and make them available for the Metropolitan Water District. The Pine Hill Reservoir, now being constructed by the city of Worcester, is also of large capacity, holding 25 per cent in excess of the average flow of its tributary watershed. It would be possible, therefore, to use this reservoir for storing water of the Ware River in addition to that obtained from its own watershed.

The chief engineer has estimated that by the diversion of the flood waters of the Ware River to the Wachusett Reservoir, an additional supply of 33,000,000 gallons per day can be assured. Should it become necessary to secure a larger and more constant supply of water from the Ware River, an extra 30,000,-000 per day could be obtained by constructing a reservoir at Coldbrook, as suggested in the report of 1895, but this would mean a reduction in the summer flow of the lower Ware River, which we have endeavored to avoid, and the flooding of valuable valley land at Coldbrook. Precedent already exists in Massachusetts for the diversion of the flood flows of one watershed to another in the case of the Salem–Beverly water supply, where Ipswich River water is led by gravity through a canal to Wenham Lake at times when the stream flow is in excess of a certain amount and when the water in Wenham Lake is below a certain level.

The Ware River Project.

We recommend, then, in accordance with the plans of the chief engineer, the immediate construction of a tunnel from the Wachusett Reservoir to the Ware River, with a diversion dam at Coldbrook, where flood water will be taken; the construction, as soon as practicable, of a plant for developing water power at the Wachusett end of the tunnel; and arrangements for pumping such water as Worcester may require either from Wachusett Reservoir or from a shaft in the tunnel into one of the streams tributary to Pine Hill Reservoir. The tunnel will be constructed wholly in rock from a series of shafts, the deepest of which will be about 575 feet, although in some places the tunnel will be 800 feet below the surface of the ground. Water will be delivered to Wachusett Reservoir by gravity. The tunnel will have a capacity of 500,000,000 gallons a day. The large size is due to the fact that it is to be used for the flood waters, and that it will be extended later on to the Swift River Reservoir.

The drainage area above Coldbrook is about 100 square miles. The population upon it is sparse and there are no large centers of population. Sanitary regulations will have to be made for this area just as for the Wachusett watershed.

The watershed contains several swamp areas, and at certain seasons the Ware River at Coldbrook has a deep brown color. The flood waters are lower in color than the dry season waters, and computations have shown that the water diverted will have little if any higher color than the aggregate of the feeders of the present Wachusett supply. Storage in the Wachusett Reservoir or in the Pine Hill Reservoir will materially reduce these colors. The water is soft and in other ways satisfactory as to quality.

The chief engineer has estimated that the cost of the first section of the tunnel to be constructed, sufficient to divert water to Wachusett Reservoir but without power development, will be about $9,500,000, based on the scale of prices which existed before the war. Present prices are higher but are falling. What they will be between the years 1924 and 1928 is a matter of conjecture. We think that they will not exceed pre-war prices by more than 30 per cent and on this basis place the probable cost of the project as about $12,000,000. This includes what we regard as a reasonable allowance for mill damages.

As the Ware River water will not be needed before 1928, there is ample time to plan and construct these works if there is no delay.

The chief engineer has also made studies of the ability of the Metropolitan District to finance this project, and has found that, if the term of the bonds is forty years and the interest not over 4 per cent, there will be no need of a general increase of water rates. Even if the financial arrangements are less satisfactory, the increase in the cost of water would not be large and would probably be of temporary duration. These financial aspects of the case are so coupled with the probable growth of population and the water consumption that they cannot be told exactly.

The Swift River Project.

Inasmuch as our recommended plan for taking an additional supply of water from the Ware River involved a future extension of the tunnel to the Swift River, and as the tunnel was to be made large enough to carry both the Ware and the Swift River supplies, it was necessary for us to be assured of the complete feasibility of the Swift River project. To construct a large tunnel to the Ware River without assurance that the extension to the Swift River was desirable would be folly. While the approximate site of a dam on the Swift River had been selected in 1895, no detailed investigations had been made, nor had the possibility of utilizing only the flood flows of the river been considered. Furthermore, at the beginning of the investigation it was considered possible that it might be advisable to recommend the Swift River project for immediate construction.

The engineering and geological studies of the project are given in considerable detail in the report of the chief engineer. He has developed a plan for utilizing the Swift River as a supply for the Metropolitan District materially different from that contemplated in 1895. It involves the construction of a huge reservoir near Enfield with a capacity of 400,000,000,000 gallons, a tunnel from this reservoir to the Wachusett Reservoir, of which the tunnel which we have already recommended is a part, and another tunnel to bring into the Swift River Reservoir the flood waters of the Millers River. He proposes also to use this reservoir, as well as the Wachusett, for storing the Ware River water, and thus secure an added quantity of water from that source. Thus, in that part of the tunnel west of the Ware River the flow would be at times westward and at times eastward. He proposes to utilize only the flood flows of all the streams mentioned, and to let the normal quantities of water pass by the dam during periods of low flow, thus interfering very little with the stream flow. He has estimated that a supply of 200,000,000 gallons of water per day can be obtained either by utilizing the flood flows of the Ware and Swift rivers when above 500,000 gallons per square mile per day, or by utilizing the flows of the Ware, Swift and Millers rivers when they are above 800,000 gallons per square mile per day. He has estimated that, on the basis of pre-war prices, the cost of the Swift River project, west of Coldbrook, would be about $38,000,000.

It is our opinion that this project should be approved as the best means of obtaining an additional supply of water for the metropolitan territory after the limit of the Ware River supply has been reached. We will not presume to say when it will be needed. For financial reasons it would be highly desirable if this construction could be postponed until 1935, when the present bonded indebtedness of the district will begin to decline rapidly. But how long the construction can be postponed must be determined in the future by the facts of water consumption rather than by financial reasons.

Nor will we presume to say what arrangement should be made between the State and the downstream mill owners; but we recommend that early steps be taken to secure some reasonable agreement in order that the inhabitants of the Swift River valley and the downstream mill owners may know what to anticipate, and hence be able to make such provision for the use of their property as seems best under the pending takings of land and water rights.

We recommend that the commission placed in charge of the construction of the Ware River tunnel be also given charge of the Swift River project, with authority to make such further engineering studies as may be necessary, and to conduct negotiations with mill owners and other property owners likely to be affected by the project.

We recommend that the reserve supplies of the Metropolitan District should be filtered when needed, and that the local communities surrounding the district should continue to utilize their supplies as long as practicable, bearing in mind the probable ultimate abandonment of some of them.

Ground Water Supplies.

Consideration has been given to the possibility of obtaining a supply of water for the Metropolitan District by means of artesian wells, but the engineers and geologists agree in the opinion that the geological formation of eastern Massachusetts is such as to preclude the possibility of obtaining an adequate supply of water from this source. We do not consider such projects worthy of serious consideration except for the development of certain small local supplies. The idea that there are great underground streams or great underground reservoirs in this part of the country is pure fiction.

Wherever attempts have been made in this State to obtain large ground water supplies at any one place, the quality of the water has suffered. Some of the largest well supplies yield water so impregnated with iron and manganese as to be very troublesome. Filtration of such water is possible, but expensive. Other ground waters contain so much carbonic acid that they are corrosive and dangerous to the public health by dissolving lead from service pipes and causing lead poisoning.

In the case of small ground water supplies, however, the facts are very different. For many reasons these small supplies are often almost ideal in quality. Even ground waters, however, must be safeguarded. If taken from a region of dense population or one of limestone formation, the dangers of pollution are by no means negligible and may be serious.

To a certain small extent it may be possible for the communities around the Metropolitan District to increase the local supplies from ground water sources.

Westfield and Deerfield Rivers.

The report of 1895 mentioned the possibility of using the Westfield and Deerfield rivers as further extensions of the metropolitan supply. We have given no study to the Deerfield River, as its possible utilization by the Metropolitan District still lies too far in the future. In view, however, of the rapid growth of the communities in the lower Connecticut valley, it seems to us that the Westfield River should be definitely eliminated from the list of sources available for the Metropolitan District and reserved for the use of the nearer cities and towns.

Cities and Towns Near but Outside the Metropolitan District.

There are 18 cities and towns now included in the Metropolitan Water District — Arlington, Belmont, Boston, Chelsea, Everett, Lexington, Malden, Medford, Melrose, Milton, Nahant, Quincy, Revere, Somerville, Stoneham, Swampscott, Watertown and Winthrop — which take water from the common source. The city of Newton is also a member of the district, but has thus far depended almost exclusively upon its local water supply. While consumption has almost reached the capacity of these works, it is not likely that Newton will call upon the district for large quantities of water during the present decade.

The cities and towns in the metropolitan territory outside of the Metropolitan Water District fall into two groups, — those any part of which are within the 10-mile radius, and those beyond it. There are 16 places within the 10-mile limit, — Braintree, Brookline, Cambridge, Canton, Dedham, Hingham, Hull, Lynn, Needham, Saugus, Wakefield, Waltham, Wellesley, Weymouth, Winchester and Woburn. The aggregate population of these places in 1920 was 391,448. They all depend upon local water supplies, the total consumption in 1920 being upwards of 34,000,000 gallons a day. The chief engineer's report gives various data for each of these supplies, with estimates of probable future needs. It is as difficult to predict the use of water in these places as it is in the case of the district itself. It does not seem to us that there is likely to be any large demand upon the common source of supply before the year 1930, but the time will surely come in the not distant future when there will be such a demand, and it will be imprudent not to anticipate it and provide for it. It must be remembered that the cities within the 10-mile radius are legally entitled to enter the district and take water from the common source at any time now if they elect to do so, providing that they comply with the fiscal requirements set by the Metropolitan District Commission.

Outside of the 10-mile radius there are other communities which are likely to desire to take water from the Metropolitan Water District before many years. Among these are Weston, Norwood, Reading, Westwood, Randolph, Holbrook, and perhaps Cohasset, Scituate and Marblehead. The total population of these places is now small, but the question of the proper method of admitting them to the district is one that should receive attention.

Water Supply of Worcester.

Following the report of an investigation made by the late Frederic P. Stearns, the city of Worcester presented a proposal to the Legislature to allow the city to take for water supply purposes a portion of the watershed of the Metropolitan Water District, pumping water from the Quinepoxet River into one of its present reservoirs. This would divert a considerable quantity of water from the supply of the district, and if taken under the financial arrangements proposed would, in our opinion, be unjust to the Metropolitan District. We believe that a better solution of Worcester's problem is the Ware River plan already described.

The Ware River water could, in our opinion, be utilized by Worcester to best advantage by allowing it to flow into the Wachusett Reservoir, obtaining the advantages which result from prolonged storage, and pumping it into such part of the Worcester system as that city may think best. Another method would be to pump it from one of the shafts of the tunnel into Pine Hill Reservoir, now being constructed. Either one would be a better method than that of taking water by the development of the Quinepoxet River. The method of pumping water from the Wachusett Reservoir would furnish water of better quality.

After the construction of the Swift River works, the water delivered to the Wachusett Reservoir from that source will be lighter in color and of better quality, thanks to its long storage, than the water of the Ware River.

The proportion of the cost of the Ware River tunnel which Worcester should pay is a matter to be determined later by the Legislature.

Cities of the Lower Connecticut Valley.

Although we have not found it possible to make any field studies as to the total amount of water supply that can be satisfactorily developed from the present water supply sources of the municipalities of the Connecticut valley, particularly those of Hampden County, study of the data already available has impressed us with the need of such studies.

In 1895 the populations of Springfield, Chicopee, Holyoke, Westfield and West Springfield were doubtless looked upon as relatively small, and our predecessors, with their eyes fixed on the future growth and requirements of the Metropolitan District, doubtless looked on the future utilization of the Westfield River watershed as of slight concern to these communities and an important potential future asset to the Metropolitan District. But to-day the conditions are different. Springfield particularly has had a rapid growth and the whole region is prospering. It is our opinion that these communities will desire to utilize the great water supply resources of the Westfield River before the Metropolitan District will need to extend its catchment area beyond the Swift River. In our opinion, the

Westfield River should be reserved for the use of the Connecticut valley cities.

Berkshire, Franklin, Hampshire and Northern Worcester Counties.

The water supply problems of these sections of the State are for the most part local, and we have not felt called upon to study them, except in a general way, in connection with the present investigation. In general, nearly all cities and towns in these sections can easily provide for their future water supply needs from near-by sources without interfering with the needs of any other communities.

Merrimack River Cities and Towns.

We are not able to make a detailed recommendation at this time concerning the water supplies of the cities and towns of the Merrimack valley. From our studies, however, we have reached certain general conclusions.

The principal Merrimack cities and towns are Lowell, Lawrence, Methuen, Haverhill, Andover, North Andover, Amesbury and Newburyport. These, with some of the less populous towns bordering the river, contain an aggregate population of about 350,000. Several of the larger communities have practically reached the limit of their available local water supply resources. The solution of their water supply problems can no longer be satisfactorily solved by these cities and towns acting separately. In our opinion they should unite in one or more groups and develop larger sources of supply which can be used jointly. Several projects have been studied by us, but we have not yet found a solution which we can recommend. Further investigations and collection of basic data are necessary. We are convinced, however, that, looking to the future, it will probably not be wise for these cities and towns to depend upon taking a common supply from the Merrimack River. It is true that the diversion of water for all of the Merrimack valley cities and towns would be much less than the diversion required for the Metropolitan District, yet it would be a considerable amount and there would be heavy damages involved.

A report made for us by Mr. H. W. Clark has shown the feasibility of filtering the water of the Merrimack River above Lowell, but there are sufficient reasons against the use of this supply. At the present time this is shown by the attitude of the citizens of Lawrence against their present supply taken from the Merrimack River above that city. Even though the water be rendered safe for use by the processes of filtration and chlorination, the citizens have repeatedly expressed repugnance against the use of a stream so heavily polluted, when it is possible for another source of supply to be obtained. Various engineering studies have been made by the different cities and towns in the valley, but not all possible joint projects have been sufficiently investigated. If the Ipswich River can be developed by the construction of large storage reservoirs, some of this water could be made available for temporary use in dry years by the Merrimack valley cities and towns. This fact has a bearing on the practicability of projects involving the further development of local sources for these cities and towns. The possibilities of obtaining water from New Hampshire, assuming that proper agreements can be made between the governments of the two States, are also deserving of further consideration.

Ipswich River.

We are not able to make a recommendation at this time concerning the water supplies of the cities of Essex County.

From time to time during the last ten years the possibility of developing a large water supply in the Ipswich River valley has been considered in engineering reports. We have not been able to make a detailed study of this problem, but it is one that should be made. The cities of Essex County will before long need to seek additional supplies of water. While we make no definite report on the Ipswich River development, we wish to call attention to the great possibilities which lie in the utilization of this stream for supplying water to a large number of cities and towns organized into a Northeastern Water Supply District. At the present time several cities have been given limited rights to take water from this stream, but these cities are growing at such a rate that before long conflicts of interest are likely to arise between them. In our opinion the proper solution of the water supply problems of the cities and towns of Essex County lies in co-operative action.

We recommend that the Legislature give consideration to the need of making further studies of the Ipswich River and the advisability of organizing a Northeastern Water Supply District.

The Water Supply Problems of Southeastern Massachusetts.

The principal communities in this section are the cities of New Bedford, Fall River and Taunton. Including the adjacent towns of Acushnet and Dartmouth, who are joint users with New Bedford, the population of this group has doubled in thirty years.

This growth shows no immediate prospect of cessation. Industrial establishments already built, but on account of temporary business depression never operated to capacity, will in the case of New Bedford result in a very sharp increase in population within a year after the resumption of industrial activity. Therefore their water supply problems deserve to be studied with special concern.

New Bedford and Taunton now take their water supplies from the Lakeville ponds, and Fall River from North Watuppa Pond, near that city. At the present rate of water consumption Fall River has practically reached the limit of its supply.

We have made careful engineering studies of the total yield, storage capacity, and sanitary and other qualities of this chain of ponds, and believe these ponds ought to be reserved in perpetuity for the water supply requirements of this group of cities and towns.

We are of the opinion that a new water district should be created to acquire and jointly preserve the water of these ponds for the benefit of the citizens of this section. At the present time New Bedford and Taunton are using less than one-third of the dry period yield of these ponds; therefore, even with Fall River and other smaller places added, the supply should be ample for a long time to come.

The problem is complicated from the standpoint of water supply because these ponds are also attractive for recreational purposes.

Although New Bedford and Taunton have wisely acquired land about their immediate sources of taking from time to time, there remain large areas privately owned and increasingly sought as sites of summer camps and for other recreational purposes. We consider the problem of prevention of pollution of these ponds a most serious one, particularly as their shallow depth produces an erroneous impression as to the degree of natural purification that takes place.

Respectfully submitted,

EUGENE R. KELLEY, *Chairman,*
RICHARD P. STRONG,
SYLVESTER E. RYAN,
ROGER I. LEE,
GEORGE C. WHIPPLE,
JOSEPH E. LAMOUREUX,
WARREN C. JEWETT,
GEORGE B. WASON,
WILLIAM H. SQUIRE,
FRANK G. HALL,
FRANK A. BAYRD,

Joint Board.

MINORITY REPORT OF JAMES A. BAILEY.

To the Honorable the Senate and House of Representatives of the Commonwealth of Massachusetts in General Court assembled.

The undersigned member of the Metropolitan District Commission, successor of the Metropolitan Water and Sewerage Board, acting under the authority of chapter 49 of the Resolves of 1919 and chapter 42 of the Resolves of 1921, has investigated and considered the questions named in said resolves, and now submits the following report.

In the investigation of the water supply needs and resources of the Commonwealth, the future requirements and available supplies of the Metropolitan Water District and the city of Worcester have been the chief subjects of study and discussion, and to this branch of the investigation the report herein submitted is limited.

It seems that Worcester will soon reach the safe capacity of her present sources of supply in a period of several successive dry years, but it does not appear that the Metropolitan Water District as at present constituted, plus such additional municipalities as are likely to seek admission, will need additional water before 1935.

The metropolitan water supply system, as recommended to the General Court of 1895 by the State Board of Health, was designed and deemed adequate by its sponsors for twenty years, or until 1915, for a population which, according to the estimate then made, would be 1,743,510 in 1915. The combined sources of supply as originally planned would yield 173,000,000 gallons daily in a series of very dry years, but a small reduction in the watershed, and legal requirements that certain amounts of water be otherwise used, reduced the safe capacity in a dry period to about 160,000,000 gallons daily. Many cities and towns within the 10-mile limit never entered the district, and the population of the municipalities comprising the district did not increase as rapidly as forecasted, so that the population served, as shown by the census of 1920, is 1,213,430, a number less by approximately 530,000 than the system as originally planned was deemed sufficient to supply, or approximately 400,000 less than the system actually created will serve.

Expressing the same idea in terms of years the population of the district in 1920 is substantially the same as the Board of Health's estimated population to be supplied about midway between 1900 (estimated population, 1,148,033) and 1905 (estimated population, 1,328,787). It follows that if a correct estimate was made in 1895, — that the system was adequate for twenty years, — the population in 1920 being approximately the number estimated for 1902 or 1903, and making due allowance for the reduction in safe yield due to the modification of the original scheme, about one-half of the estimated twenty-year period has elapsed and about one-half remains.

But in fact, the growth of population has been much less than was forecast by the Board of Health. For example, the estimated population of Boston in 1920 (including Hyde Park annexed since 1895) was 848,851, as contrasted with the census of 748,000. The forecast for Everett was 63,358, and the census 40,120, and nearly all the cities and towns fell considerably below the estimated population. Obviously the smaller the number of people served the longer a given supply of water will suffice.

The population of the district in the years ahead is not likely to increase so rapidly as in the past. As a result of the war and consequent destruction of property, world-wide upheaval and disorganization of industry and commerce, conditions for some time are likely to be similar to those which prevailed for a considerable period beginning several years after the Civil War. During hard times marriages decrease and births diminish. The census of Boston and its suburbs indicated a falling off of 50 per cent in the normal rate of increase of population in the period above mentioned. Furthermore, immigration, which in the recent past has supplied a large proportion of the inhabitants of the Metropolitan District, has been severely restricted by law. This will check the tendency of population to increase. Tables of annual birth rates in Massachusetts indicate that the birth rate among the foreign born is three times that among the native born. The statistician from whom these figures are quoted concluded that the native-born population of Massachusetts was not maintaining itself, and in any event it seems clear that a lowering birth rate in Boston and vicinity may be expected in the years ahead. It follows that the ordinary estimates of future population in the district as a basis for determining future needs for water must be greatly modified.

In relation to the per capita consumption of water in the Metropolitan District an exhaustive study and accurate forecast were made in 1895 by Dexter Brackett. He stated that the quantity to be used in estimating the requirements for a twenty-year period was 100 gallons, of which 35 were for domestic use, 35 for trade and manufacturing, 5 for public use and 25 for waste. In the year 1921 the per capita consumption in the district was about 95 gallons, and in only two of the last nine years has it risen above 100 gallons, despite the feverish manufacturing activities during the war and the coldest winter in a long period.

In the annual report of the Metropolitan District Commission for the year 1920 appears the following paragraph from the report of the chief engineer of the Water Division: —

> Now that the war is over, and conditions are returning to normal, there appears to be no reason why thorough inspection by local officials, and the unrestricted enforcement of the legislation of 1907 for the installation of meters on service pipes, should not reduce the per capita consumption of water to 90 gallons per day, which was sufficient for all purposes in 1915.

The per capita consumption of water daily in gallons in two groups of cities, taken from the latest available reports, was as follows: —

Group 1. — *Ten Massachusetts Cities not in Metropolitan Water District.*[1]

Cambridge	94
Lowell	60
Lawrence	47
New Bedford	80
Fall River	46
Taunton	82
Worcester	84
Waltham	61
Lynn and Saugus	71
Springfield	104

[1] Taken from last published report of Department of Public Health.

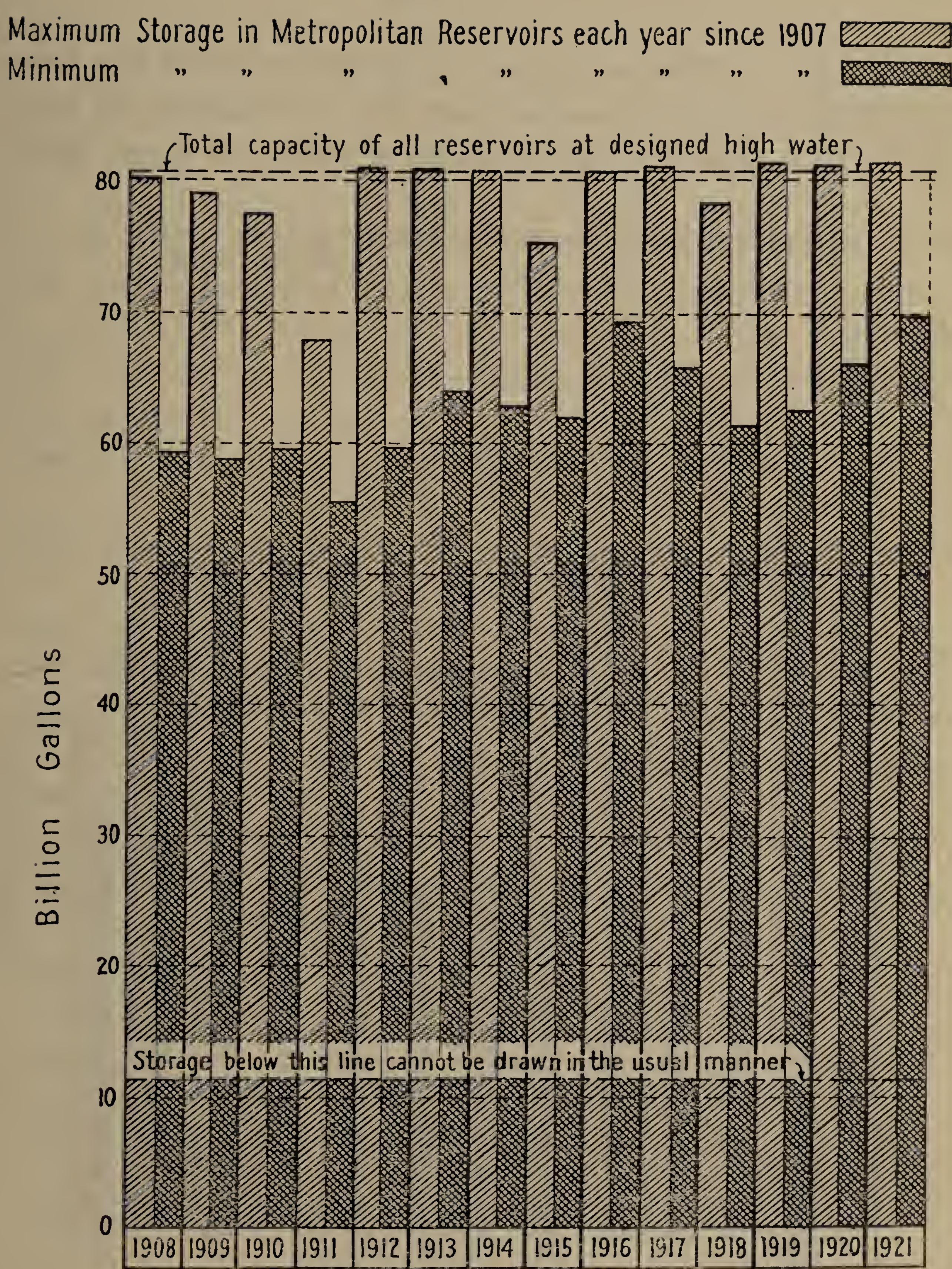
GROUP 2. — *All Cities in Metropolitan Water District, 1921.*

Boston	112
Chelsea	70
Everett	86
Malden	49
Medford	45
Melrose	57
Quincy	86
Revere	65
Somerville	73

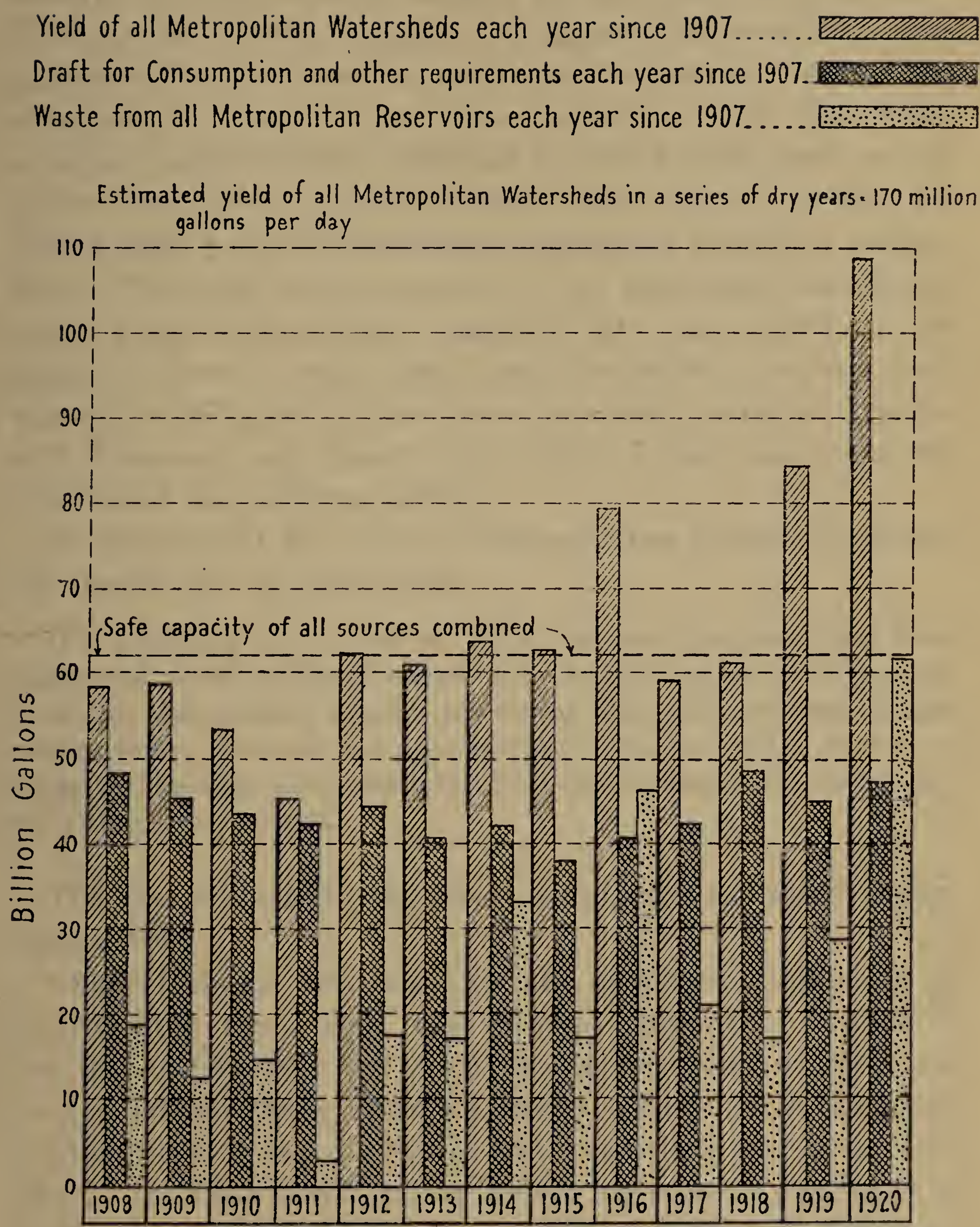
In the light of the above facts there appears to be no sound basis for forecasting the daily per capita consumption of water in the Metropolitan District at more than 100 gallons in the next ten years; and there is a reasonable basis for the belief that when Boston has metered about 40,000 services now unmetered the per capita consumption of Boston may be reduced to considerably less than 100 gallons, thereby greatly lowering the average consumption of the inhabitants of the district. The gradual installation of meters, required by chapter 524 of the Acts of 1907, but suspended by law in Boston during the war, has resulted in bringing down the total water consumption of the entire district to substantially the amount used by the smaller population of fifteen years ago. About 75 per cent of all services are now metered, and in order to justify an invasion of central or western Massachusetts to obtain water for Boston and vicinity every reasonable effort ought to be made to prevent needless waste of the present supply.

The safe yield of the present sources of supply available for use in the Metropolitan Water District in a series of very dry years is about 160,000,000 gallons per day, the equivalent of 100 gallons to each of 1,600,000 persons, a number which probably will not be reached before 1935. A reduction to 90 gallons would care for the needs of 177,778 additional persons, and no one can reasonably doubt that 10 gallons waste per person daily can be eliminated for a brief period, in case of urgent necessity, by a people who survived gasless Sundays, heatless Mondays and rationed sugar, to each of whom 90 gallons of water daily would still be vouchsafed for drinking, bathing and other purposes.

I.


Maximum Storage in Metropolitan Reservoirs each year since 1907
Minimum " " " " " " " " "
Total capacity of all reservoirs at designed high water
Storage below this line cannot be drawn in the usual manner
Billion Gallons
80
70
60
50
40
30
20
10
0
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921

II.



Yield of all Metropolitan Watersheds each year since 1907
Draft for Consumption and other requirements each year since 1907
Waste from all Metropolitan Reservoirs each year since 1907
Estimated yield of all Metropolitan Watersheds in a series of dry years = 170 million gallons per day
Safe capacity of all sources combined
Billion Gallons
110
100
90
80
70
60
50
40
30
20
10
0
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920

Since the Wachusett Reservoir first filled in 1908 there has been an abundant supply of pure water for all the inhabitants of the district. The reservoir has filled and overflowed in nine of the fourteen years. During this period in several years the amount of water wasted, because all the reservoirs were overflowing, has nearly equaled the amount delivered into the aqueducts for use; and in two years the amount wasted has exceeded the amount used. The largest reservoir alone holds a supply approximately sufficient to care for the needs of the entire district for one and one-half years, even if no rain fell during that period, eliminating evaporation from this calculation. The total storage capacity is so great that the district easily passed through four successive dry years, 1908–11, the period of lowest water yield since the Sudbury records were started in 1875, and in the last of the four years the Wachusett Reservoir was drawn down only 17 feet, and promptly overflowed the following spring.

In their report for 1911 the Metropolitan Water and Sewerage Board say of this period: —

> It is gratifying that, notwithstanding the almost unprecedented small amount of rainfall following a series of dry years unknown to the past records, the Metropolitan District has during the past year been brought neither to inconvenience nor apprehension on account of the scarcity of water, and has been able to assist two other communities in the emergencies which they have suffered.

The charts illustrate the actual workings of the water supply since 1908.

Chart I shows the maximum and minimum storage in all metropolitan reservoirs. The smallest amount in storage in the last of four very dry years, at the low point of 1911, was over 55,000,000,000 gallons, an amount greater than the entire consumption of the district in any year since the large basin filled. In other words, at the lowest mark there was water in storage sufficient for more than one year, without further rainfall.

Chart II shows that in no year has the draft equaled the yield of that year. It shows, also, some waste every year, and waste in two years exceeding the amount used.

In relation to the suggestion that a considerable number of cities and towns, not now members of the Metropolitan Water District, both within and without the 10-mile limit, must be admitted to the district or take water from it in the near future, the following observations are submitted.

The natural desire of municipalities to run their own affairs and own and manage their own water supplies is illustrated by the fact that of the 28 cities and towns included in the district proposed to be created by the bill presented to the Legislature of 1895, 15 preferred to remain out. Since that year only 1 city (Quincy) and 6 towns have applied for admission to the district, and the population in 1920 of all the municipalities added to the district in more than a quarter century was only 100,080, or an average increase per year of about 3,700. Within the last two years the only inquiries about terms of admission have come from Braintree and Weymouth. It is doubtless true that a few towns may require some water from the Metropolitan District in the near future, and it is also true that the district can supply them, as their requirements are not large. The assertion that Cambridge, Brookline and Woburn will find it necessary to take water from the district within the next few years is not agreed to by the responsible officials of those municipalities; and in any event, cities and towns which have shied away from the district when the cost of the Wachusett Reservoir, including all water and other damages, was about $12,500,000, are not likely eagerly to embrace the opportunity to come in when an expenditure of $59,500,000 is recommended to gather and bring additional water to the same reservoir. It seems, therefore, reasonably safe to predict that in the next 10 years no great increase will be made in the population of the district by the addition of cities or towns within or just outside the 10-mile limit.

In order to care for its own needs and to admit or help near-by communities the Metropolitan Water District for a considerable period will be required only to continue the policy of metering services, and provide for the filtration of its poorer sources of supply. So abundant have been the better sources of supply that it has been unnecessary for ten years to use water from the southern Sudbury reservoirs, having a combined dry weather capacity of 30,000,000 gallons daily, and Cochituate, with a capacity of 10,000,000 gallons, has been kept as an emergency supply and drawn on moderately at irregular intervals. Obviously it is cheaper to filter the water in near-by reservoirs than to construct new and distant reservoirs, and, were it not for Worcester's needs, the next considerable expenditure by the Metropolitan Water District would be for filtration of the waters of the southern Sudbury reservoir and Cochituate.

Within a few years Worcester will probably require more water as a safeguard against a long period of excessive drought, and her problem is interwoven with the future requirements of the Metropolitan District. The officials of the city have repeatedly urged that it is just and expedient that Worcester should be granted by legislative act the waters on one-sixth of the Nashua watershed, in the Quinapoxet area, now flowing into the Wachusett Reservoir, which waters were lawfully taken, paid for, and are now owned by the Metropolitan Water District. In a report of the Commission on Additional Water Supply for the city of Worcester (Senate No. 346 of 1920), — the mayor, city engineer and city solicitor comprising the commission, — it was recommended "that the city of Worcester be authorized to increase its water supply from the said Quinapoxet River area substantially as provided in the draft of a bill accompanying the report." This bill has been taken from the files and is now pending in the Legislature. The following are some of the reasons why this bill ought not to be enacted: —

1. Pumping of the water so obtained will be necessary for all time, — a wasteful and unnecessary method of securing a supply.

2. The question of Worcester's rights in the Nashua River watershed was threshed out by the Legislature, a part of the watershed which yielded water by gravity to Worcester was set off to her, and the remainder given to the Metropolitan Water District.

3. The Wachusett Reservoir, with its costly dam and dikes, was planned and constructed on the basis of receiving, storing and delivering the water from all the watershed now tributary to it.

4. The diversion to Worcester of a large part of the flow of

the Quinepoxet River will cause a material deterioration in the quality of the water entering the Wachusett Reservoir.

5. If the pending act is passed Worcester will pay less than $400,000 for the right to take the water which she seeks. As the yield of the territory in question is about 6,570,000,000 gallons per year, and as the water taken is worth $30 per million gallons, the capitalized value, on a 5 per cent basis, to the Metropolitan Water District is about $4,000,000, and the cost of the same amount of water from new sources will be a much larger sum. In short, the Metropolitan Water District can better afford to make a gift of millions of dollars to the city of Worcester than to have Worcester take from the district the watershed sought by her.

6. When one community (Worcester) needs more water in the near future, and a group of other communities (the Metropolitan District) will need more water some years later, it is bad public policy to permit the one to strip from the other a large fraction of its supply for all time.

As Worcester will need additional water at a much earlier date than the Metropolitan District, and as the filtering of the Southern Sudbury Reservoirs and Lake Cochituate will not help that city, it is recommended that the considerable expense of constructing filtration plants be not incurred at present, but that the Metropolitan District and Worcester prepare to go jointly to the Ware River. A large supply of water may there be obtained at moderate cost.

Inasmuch as the principal study has been given to the Swift River project, it is apparent that much engineering and other work must be done to determine the best method of taking the waters of the Ware. It is not yet satisfactorily determined whether any considerable reservoirs should be constructed on the Ware, and if any are to be constructed the exact location will require detailed investigation and careful consideration. It may be that Worcester can be supplied by gravity through a high-level tunnel, in a manner advantageous to all concerned, or it may be better to pump water for all time several hundred feet from a low-level tunnel.

Considerable time is required also for an accurate and complete study of the matter of damages for the diversion of water, and the possibility of obtaining agreements with the owners of mills and power plants before the takings and construction work are authorized.

It is therefore recommended that a moderate appropriation be made for a complete study of the problem of taking water from the Ware, and that the taking of lands and water and construction of works be not authorized at this session of the Legislature.

All of which is respectfully submitted.

JAMES A. BAILEY.

JANUARY 27, 1922.

EXPENDITURES FOR WATER SUPPLY INVESTIGATIONS UNDER CHAPTER 49 OF THE RESOLVES OF 1919.

Appropriations made in 1919 and 1920		$82,500 00
Expenditures to January 28, 1922:		
Salaries of engineers and assistants, experts, clerks and stenographers	$52,471 01	
Traveling expenses	13,463 16	
Observers	722 81	
Borings and test pits for dam sites	14,276 38	
Stationery	367 74	
Furniture and supplies	530 04	
Field office	74 36	
Instruments and repairs	58 06	
Prints, books and maps	210 60	
Labor	58 26	
Miscellaneous	246 74	
Balance	20 84	
		$82,500 00

Note. — This statement includes all items of expenditure approved by the Joint Board.

RECOMMENDATIONS FOR LEGISLATION.

The resolve under which the Commission was established authorized the presentation of drafts of legislation to carry out its recommendations. There are appended two resolves drafted for this purpose. A draft of a bill creating a proposed water district for southeastern Massachusetts has been outlined. When the Commission came to consider a draft of legislation for the extension of the metropolitan water supply it became apparent that no satisfactory suggestions could be made to the Legislature under existing circumstances, especially since such suggestions would involve the probable future relations of other cities and towns to the district. Feeling, however, that in its report the Commission has clearly outlined the basic principles upon which such legislation should be drawn, the Commission expresses the hope that the General Court will make such provision as may be necessary to have drafts made and presented.

Resolve to provide for Investigating the Matter of a Water Supply for the Cities and Towns of Essex County and Adjacent Portions of Middlesex County.

Resolved, That the state department of public health be and hereby is authorized and directed to investigate the water supply needs and resources of the cities and towns of the county of Essex and of municipalities in adjacent portions of the county of Middlesex. The said department shall determine the best method of supplying said municipalities with water and of protecting the purity of the water. Said department shall make such surveys as may be necessary to determine upon sites suitable for storage reservoirs in the watershed of the Ipswich river and of the Merrimack river within the limits of the state, with special reference to developing the highest practicable and economical yield for water supply purposes of the Ipswich river and its tributaries for the use of the cities and towns, or groups of cities and towns, which may reasonably be supplied therefrom, whether within the limits of Essex county or in adjacent parts of the state. Said department shall consider the practicability of the development of water supplies for any of the cities and towns, or groups of cities and towns, in the valley of the Merrimack river by the use of any natural ponds now used as sources of water supply or any ponds or reservoirs which may be made available for the purpose, either alone or in connection with waters diverted from the watershed of the Ipswich river. Said department shall consider and examine proposed sources of water supply already recommended for the use of any of the municipalities in Essex county or adjacent parts of Middlesex county in previous reports, whether by state commissions or local authorities.

The department may employ such engineers, geologists, and other experts and assistants, and may incur such expenses, as may be necessary to carry out the provisions of this resolve and as may be approved by the governor and council.

The commission shall report to the general court on or before the second Wednesday in January in the year nineteen hundred and twenty-three, and shall include in its report maps and plans showing proposed reservoirs or water supply systems, and may submit drafts of legislation which it may deem expedient to carry out its recommendations.

Resolve relative to the Measurement of Certain Watersheds recommended for Water Supply.

Resolved, That the state department of public health be and hereby is authorized and directed to install such measuring and recording devices as may in its opinion be necessary accurately and permanently to record the amount of water flowing at all times in the Ware river, the Swift, Millers and Westfield rivers, or any tributaries thereof, at or as near as practicable and above any proposed point of taking or diversion of water from said rivers or tributaries for the water supply of the metropolitan water district or any other municipality, and all records so taken shall be kept on file by the said state department of public health, shall be open at all times to inspection by the public, and copies of the same shall be published in its annual reports.

Said department shall also establish and maintain a sufficient number of rainfall stations in the watersheds of said rivers suitably located to show accurately the average rainfall within the said watersheds above the points at which stream-flow measurements are made.

Draft of an Act creating the Southeastern Massachusetts Water Supply District.

Section 1. A board of commissioners is hereby created which shall be known as the Southeastern Massachusetts Water Supply Board.

Said board, acting for the commonwealth, shall acquire, improve, maintain and operate a system of water supply to include certain ponds hereinafter named situated in the towns of Lakeville, Middleborough and Freetown, in Bristol and Plymouth counties, substantially in accordance with the recommendations of the joint board on water supply needs and resources of the commonwealth contained in their report to the legislature of the year nineteen hundred and twenty-two, and shall provide thereby a supply of pure water for the following-named municipalities and the inhabitants thereof, to wit: the cities of Fall River, New Bedford and Taunton, and the towns of Freetown, Lakeville, Acushnet, Dartmouth, Fairhaven, Dighton and Raynham, which cities and towns shall constitute the southeastern Massachusetts water supply district.

The said board shall secure, keep, develop to their full extent the said waters and protect their purity; shall on application admit to the district the towns of Swansea, Somerset or Westport or any municipality any part of which is within ten miles of the boundary point marking the corner of Lakeville, Freetown and Rochester, and including the towns of Swansea, Somerset, Westport, Berkley, Bridgewater, Middleborough, Carver, Wareham, Marion, Rochester, Mattapoisett and Fairhaven, into said water supply district, and furnish water for the same, on the terms prescribed by this act; shall on application furnish water for any water company owning the water pipe system in any town within said ten miles, on such water company assuming the assessment of the town, if any, and making such payment of money as said board may determine; and may from time to time furnish water for any other city, town or water company on such payment of money as said board may determine. All payments of money aforesaid shall be used for the payment of bonds or interest thereon issued under authority of this act or for maintenance.

APPOINTMENT AND ORGANIZATION OF BOARD.

SECTION 2. The governor, by and with the consent of the council, shall appoint three commissioners who shall constitute the southeastern Massachusetts water supply board no two of whom shall be residents of the same municipality. Said commissioners shall hold office one for the term of three years, one for the term of two years, one for the term of one year, beginning with the first Monday in May in the year nineteen hundred and twenty-two, and annually thereafter the governor shall appoint as aforesaid one member of said board to hold office for a term of three years beginning with the first Monday in May in the year of his appointment. The governor, with the consent of the council, may remove any member of said board, and may appoint for the residue of the term, in the same manner in which the original appointment was made, a commissioner to fill any vacancy occurring by removal, resignation or otherwise. The chairman of said board shall receive a salary of per year, and the other members a salary of per year.

OFFICERS AND ACCOUNTS.

SECTION 3. Said board shall from time to time appoint such agents, officers, clerks and other employees as said board may deem necessary; shall determine the duties and compensation of such appointees, and may remove the same at pleasure, and may employ counsel; shall at all times keep full, accurate and separate accounts of the doings, receipts, expenditures, disbursements, assets and liabilities of said board, and include an abstract of the same in an annual report to the general court on or before the third Wednesday in January in each year.

TAKING OF PROPERTY.

SECTION 4. Said board may take by eminent domain under chapter seventy-nine of the General Laws, or acquire by purchase or otherwise, the waters of Long, Assawompsett, Pocksha ponds in the towns of Freetown, Lakeville, Middleborough, but shall allow not less than
to flow from Assawompsett Pond into the Nemasket River.

Said board may also take as aforesaid or acquire as aforesaid any or all of the ponds or water courses tributary to any of the aforesaid ponds excepting Great Quittacas, Little Quittacas and Elders ponds and their tributaries; shall take such water rights of the cities of Taunton and New Bedford in said Assawompsett, Long and Pocksha ponds, as they deem necessary, connected with said waters, and may take any lands in fee, easements, rights and any other property, excepting the pumping station of the city of Taunton now situate on Assawompsett Pond and lands adjacent thereto, that said board may deem necessary or desirable for carrying out the powers and duties conferred upon them by this act.

TAKING BY RIGHT OF EMINENT DOMAIN.

SECTION 5. Said board, to take any property by right of eminent domain, shall sign and cause to be recorded in the registry of deeds for the county and district in which the property to be taken is situated a statement containing a description thereof, as certain as is required in a common conveyance of land, and stating that the same is taken for the southeastern Massachusetts water works; and upon such recording the ponds, works, lands, waters, easements, rights and other property described in said description shall be taken for the commonwealth. Said board, upon entering upon any land for the purpose of using the same for carrying out any of the purposes of this act, shall sign and cause to be recorded in the registry aforesaid a statement containing a general description of the land and the purposes for which it is to be used, and the probable time for which the same is to be used, and after they have taken any property under the right of eminent domain shall notify the owner thereof, and on the request of the owner within three years after such taking shall, within thirty days after such request, furnish him with a plan or description in writing of his land or other property so taken.

OPERATION AND MAINTENANCE OF WORKS, CARE AND CONTROL OF PONDS, LANDS AND WATERS.

SECTION 6. Said board shall have the exclusive right and control over all ponds and reservoirs used by them in supplying water, and may order all persons to keep from entering in, upon or over the waters thereof and the lands of the commonwealth, city or town surrounding the same; may inspect the water works and fixtures in any city or town supplied wholly or in part from the works under their charge, and may take all proper measures to determine the amount used and wasted and to prevent the improper use or waste of water.

USE AND SALE OF PROPERTY.

SECTION 7. Said board may sell at public or private sale or may exchange any property, real or personal, or any easements, whether taken by eminent domain or otherwise, no longer needed for works under their charge or may from time to time lease any property not then so needed; and may in their discretion, by lease, license or other agreement, permit the construction and maintenance on any land under their control of towers, poles, wires and other structures for the purpose of transmitting electric power over lands and waters of the commonwealth held for water supply purposes; provided that, in the opinion of the board, such lease, license or agreement will not affect or interfere with the water supply; and provided, further, that no lease, license or agreement shall be given or made for a period of more than fifteen years. The proceeds from the operations of said board shall be paid into the treasury of the commonwealth.

LOCATION OF MUNICIPAL PUMPING PLANTS AND THEIR APPURTENANCES.

SECTION 8. Said board shall (subject to the provisions of section seventeen) agree with any city or town as to the location of new pumping plants and appurtenances for pumping water from the ponds or reservoirs which it may control, and it shall fix the location of all new intakes, pumping stations and their appurtenances on the aforementioned ponds, and shall either prepare or approve the plans for the same, and the maintenance of all pumping stations and their appurtenances where the water is drawn directly from the said ponds and reservoirs under the control of said board shall be subject to its approval.

EXPENSES OF WORKS, DAMAGES AND POLICE PROTECTION.

SECTION 9. Said board shall incur such expenses as they deem necessary in taking, constructing, operating and maintaining the water works under their charge; may agree with the party injured, upon the damages sustained by the taking or use of any lands, ponds, reservoirs, water sources or other property, or the cancellation of contracts, as aforesaid; the damages sustained by any person or corporation in property by any taking of property or by any change of grade, alteration or discontinuance of any public way or by the construction or maintenance of any reservoir or other work, or by the interference with the use of any water, or by any other act or thing done by said board under this act; shall save harmless the several cities and towns within which any road, street or way is dug up as aforesaid, against all damages for injuries resulting from a defect or want of repair in any road, street or way, caused by such digging up, or by constructing, laying, maintaining or repairing any aqueduct, conduit, pipe, wires or other works therein, and shall furnish without charge to all towns within which any work is done under authority of this act such additional police protection as may be necessary in consequence thereof; provided that said board shall have due and reasonable notice of the claims for such damages and opportunity to make a legal defence thereto.

PETITIONS FOR DAMAGES IN SUPERIOR COURT.

SECTION 10. If said board and a city, town, person or corporation cannot agree upon any damages sustained as aforesaid, they may, except in the case in which payment is otherwise provided for in this act, within two years after the day of the taking of any land, water, easements or other property, or of the use of any property, or of the making of any change of grade, alteration, discontinuance or location of a way, or of the doing of any other act or thing causing the damage, file in the office of the clerk of the superior court for the county in which the property taken, used or affected in value by such taking or other act of said board is situated, a petition signed by the petitioner or the attorney of the petitioner, for a jury to determine such damages, and thereupon, after such notice as said court shall order, the damages so sustained shall be determined by a jury in said court in the same manner as damages for lands taken for highways are determined. In determining any damages caused by any change of grade or discontinuance of a public way, or the substitution of a part of a public way for another part, there shall be taken into account any benefit to the party injured received from this act and everything done thereunder. Interest shall be included in such damages from the date of the taking, or the doing of the act or thing causing the damages, and costs shall be taxed and execution issued as in civil cases, against the commonwealth in case the petitioner prevails and against the petitioner in case he does not prevail. Damages for the temporary use of or injury to property, may, on the request of the petitioner, be assessed by monthly payments, to be continued so long as the property is used.

SOUTHEASTERN MASSACHUSETTS WATER LOAN.

SECTION 11. The treasurer and receiver general shall, from time to time, on the request of said board, issue negotiable bonds in the name and behalf of the commonwealth under its seal to an amount not exceeding   designated on the face thereof, Southeastern Massachusetts Water Loan. Said bonds shall be deemed a pledge of the faith and credit of the commonwealth, and shall be issued in accordance with the provisions of chapter twenty-nine of the General Laws.

PAYMENTS BY STATE TREASURER — ADVANCEMENTS TO DISBURSING OFFICER.

SECTION 12. Said treasurer shall apply the proceeds from the sales of property made as hereinbefore provided, and the proceeds from the sales of said bonds, exclusive of the amounts received from premiums, to the payments for the property taken by said board, the payment of the damages aforesaid and the payment of the expenses of construction of said water works, and the other payments specified in this act, and shall apply any assessments hereinafter provided for paid by the cities and towns, and the proceeds from the operations of said board exclusive of the proceeds from sales of property, to the payment of the interest and expenses of maintenance and operation of said water works, and shall take the balance required for said payments, if any, from the proceeds of said bonds, and shall apply the surplus, if any, to the payment of said interest, principal requirements and expenses, for the following year. Said treasurer shall advance to such person as shall have been designated by said water board and shall have given a bond to said treasurer with sufficient sureties, to be approved by the auditor of the commonwealth, in the sum of ten thousand dollars, such sums, not exceeding ten thousand dollars at any time, as said person may certify to be necessary to enable said board to make direct payment upon the pay rolls and other accounts of said board, and such person shall, as soon as may be after expending any sum so advanced, and in all cases within thirty days from the receipt of any such sum, file with the auditor a statement in detail of the moneys expended subsequent to the last previous accounting, approved by said water supply board, and, where it is practicable to obtain them, also file receipts or other like vouchers of the person to whom the payments have been made.

ESTIMATE AND APPORTIONMENT OF ANNUAL EXPENSES.

SECTION 13.

CONTROL AND DISTRIBUTION OF WATER BY CITIES AND TOWNS.

SECTION 14. The water board, water commissioners or superintendent of any city or town in the southeastern Massachusetts water district shall for their respective cities or towns continue to have full charge and control of the water sources, water and water works owned and used by said city or town except where otherwise specifically provided in this act. Said local water board, water commissioners or superintendent shall distribute and control the use of the water so furnished and apply meters and extend the pipes and other works as said local water board, water commissioners or superintendent may deem expedient; shall keep the pipes, fixtures and other works under their charge in good condition and repair, but shall not expend in any year more than the amount appropriated by the city or town therefor. Said local water board, water commissioners or superintendent, or the mayor or selectmen, as existing laws provide or future laws may provide, shall determine the rate to be paid for water by the owner of the premises to which the water is furnished, or by the person or persons using the water. Any local water board, water commissioner or superintendent as aforesaid shall for the water works under his charge do all the acts and things relating to buildings, machinery, roads, conduits, aqueducts, pipes and drains, which said local board is authorized to do for the water works under their charge, and may take lands therefor in fee or otherwise, and shall do all such acts and things and make all such takings in the manner in which said local board is authorized to do similar things, and the damages sustained shall be recovered of, and paid by, the city or town for which such local water board, water commissioners or superintendent are appointed or elected, in the same manner as damages caused by similar acts of said southeastern Massachusetts water supply board are recovered of, and paid by, the commonwealth.

Section 15. The income received in each city or town from the water works under the charge of its water board, water commissioners or superintendent, shall be applied to the payment of the expenses of maintenance and operation incurred by said water board, water commissioners or superintendent; to the payment of the interest and sinking fund requirements of all bonds and the payment of serial bonds as they become due, of the city or town issued on account of the water works of such city or town; to the assessment of the city or town to be paid to the treasurer of the commonwealth as hereinbefore provided; to the expenses of the extension of the works; and the balance, if any, as the city or town may determine. If such income in any year shall not be sufficient for said payments, the balance required therefor shall be raised by taxation or by loan, as the city or town may determine; and the city or town is hereby authorized to assess such taxes and make such loans without further authority from the legislature.

SPECIAL PROVISIONS AS TO WATER SUPPLIES IN WATER DISTRICT.

Section 16. No municipality, including Swansea, Westport and those within ten miles of the existing boundary point marking the corner of Lakeville, Freetown and Rochester, or any water company owning a water pipe system in any such municipality, shall, except in case of emergency, use, for domestic purposes, water from any source not now used by it except as herein provided or as shall be hereafter authorized by the legislature. If any town or towns in said district shall take the franchise, works and property in such town or towns of any water company, the compensation to be allowed and paid therefor shall not be increased or decreased by reason of the provisions of this act. No town in said water district now supplied with water by a water company owning the water pipe system in such town shall introduce water from the southeastern Massachusetts water supply works until it shall first have acquired the works of such company.

APPROVAL OF STATE DEPARTMENT OF PUBLIC HEALTH AND SANITARY PROTECTION OF SOUTHEASTERN MASSACHUSETTS WATER SUPPLY.

SECTION 17. No land shall be taken for preserving the quality of the water or subsequently exchanged or sold, nor shall any plan for the construction of works for improving the quality of the water, or adding to or extending the sources of supply or constructing new intakes, filters or other works in connection with said ponds or any works to take water therefrom under the provisions of this act to be put into effect, without first obtaining the advice and approval of the state department of health.

PROTECTION OF WATER SUPPLY AND WORKS OF CITIES AND TOWNS.

SECTION 18. No person shall take or divert any water of a water supply of any city or town in said water district from any water source, reservoir, conduit or pipe used for supplying such water to or in any such city or town, or occupy, injure or interfere with any such water, or with any land, building, aqueduct, pipe, drain, conduit, hydrant, machinery or other work or property so used, and no person shall corrupt, render impure, waste or improperly use, any such water.

ENFORCEMENT OF WATER ACT AND RULES AND REGULATIONS.

SECTION 19. Said southeastern Massachusetts water supply board, and their employees designated for the purpose, shall enforce the provisions of this act, and of the rules, regulations and orders made thereunder, and may enter into any building, and upon any land, for the purpose of ascertaining whether sources of pollution there exist, and whether the provisions of this act and of the rules, regulations and orders made as aforesaid, are complied with.

SECTION 20. The supreme judicial court or any justice thereof, and the superior court or any justice thereof, shall, in term time or vacation, on the petition of said board or any city, town, corporation or person interested, or of the attorney of any such petitioner, have jurisdiction in equity or otherwise to enforce the provisions of this act, and of any rule, regulation or order under the authority of this act, and to prevent any violation of said provisions, rules, regulations or orders.

PENALTIES.

SECTION 21. Whoever shall do any of the acts herein prohibited, or shall violate or refuse to comply with any rule, regulation or order made under the authority of this act shall, on complaint or indictment therefor and conviction thereof, be punished for each offence by a fine not exceeding five hundred dollars, to be paid to the commonwealth, or by imprisonment not exceeding one year in the house of correction, or by both such fine and imprisonment.

REPORT OF CONSULTING ENGINEER.

January 6, 1922.

Dr. Eugene R. Kelley, *Chairman, Commission on Water Supply Needs and Resources of the Commonwealth, Boston, Mass.*

Sir: — During the past eighteen months I have followed the studies and investigations made by your chief engineer and his staff, the results of which are given in his excellent report, and have been able to give advice and assistance while the various problems were under discussion, at the time when such advice and assistance would be most valuable and effective.

To review his report now would result largely in stating in other language what has already been stated, and could serve no useful purpose. I have, therefore, confined my report to a statement of a few basic facts, in an attempt to emphasize the gravity of the situation and give my opinion as to the feasibility and practicability of the entire project as recommended.

The present consumption and available supply, the rate of growth of population, the per capita daily use, and the time necessary to construct a new supply to the point where additional water becomes available are the factors which determine the question as to when active steps must be taken to prepare plans and begin their execution. The estimated population to be supplied in the future and the availability and capacity of possible sources of supply determine the choice of source.

The report presented by the chief engineer has gone into all these points with painstaking care and thoroughness. He has presented the facts and his conclusions in a comprehensive way, and they are convincing. I have been in close touch with his investigations and studies, and endorse his findings, which are conservative. Higher estimates of consumption might well have been made for the purpose in hand.

Engineers who have studied the subject recognize that there is a slow and progressive increase in the daily per capita use of water, whether the supply is delivered through meters or otherwise, and to this fact due consideration must be given in making forecasts.

The Metropolitan District is now in the position where the slack has practically all been taken out by the introduction of meters, and no other remedy for reducing the consumption can be applied except a rationing of the water. This, of course, is impossible, and the only known solution is to be found in an increase of the supply.

Estimates as to just when an addition to the water supply will be needed may differ by a few years, as they depend on natural phenomena which vary widely from year to year, such as rainfall, drought, industrial activity and hard times, heat and cold, etc. The one thing essential is that the new supply shall arrive in time so that the people may not suffer the hardships of a deficiency.

Water is absolutely essential to life and to the growth, health and prosperity of a community. It gives the greatest return value for the least outlay of any one of the necessities which are essential to the subsistence and happiness of a people, who pay — and pay willingly — the entire expense. A few cents paid every day by each family is sufficient to meet all charges and to extinguish the debt.

It is unthinkable that the public should be compelled to assume the hazard of a shortage of water, or even be put to any inconvenience respecting the sufficiency of their supply. In the present situation it is entirely certain that they will in the near future suffer a shortage unless plans are progressed and work on an addition to the supply is begun at an early date.

The total safe available supply is about 155,000,000 gallons daily. The average consumption for the past three years, 1918 to 1920, inclusive, was 125,000,000 gallons daily. The balance, 30,000,000 gallons daily, is only equal to about seven years' normal increase in consumption. The time necessary to construct the required works, so that some additional water will be made available, is seven years from the time the contracts are executed.

A study of the past shows that additions to the water supplies of cities and communities have never been completed too soon, and that in most, if not all, cases the people have been compelled to suffer the trials of a deficient supply.

The chief engineer has recommended that the next increment of the water supply should come from a point about 25 miles west of the present Wachusett Reservoir, which, at the time of its construction, was built of very large capacity and with a view to the probability that at a later time additional water would be secured from areas further to the west. The aqueduct leading from it to Sudbury Reservoir has a surplus capacity of about 200,000,000 gallons daily over the quantity that can be furnished by Wachusett Reservoir.

It is now proposed to build a large storage reservoir on the Swift River above West Ware, in which would also be stored water from portions of the Millers and Ware rivers. The location proposed is an extraordinarily favorable one, because an immense storage can be created by the construction of two moderate-sized dams. The drainage areas are sparsely populated, and the water is very pure and admirably suited for domestic use. The conformation of the ground is particularly advantageous, and portions of both the Millers and Ware rivers can easily be diverted into this reservoir.

The aqueduct line to the Wachusett Reservoir will be about 25 miles long, largely in tunnel.

The investigations which have been made are entirely sufficient to show the practicability of the whole project and to serve as a basis for the cost estimates. I have given particular and continuous attention to both of these features, and can state that the construction of the dams is entirely practicable and will involve no unusual or insurmountable problems. The aqueduct also is entirely feasible and not unlike other tunnel work, an immense amount of which has been done in this general vicinity.

The estimates of cost have been made to conform to present conditions, and I believe them to be conservative and sufficient to cover all of the construction work.

Approval of this plan should settle the water problem of the Metropolitan District and contiguous areas for a long time to come. It also has the advantage that at some later date, if required, additional supplies of water may be secured with comparatively small expenditures. It is by all odds the best source from which water of a quality suitable for domestic use can now be secured in large quantities and be made available for meeting the urgent needs of the large and increasing population of Boston and the metropolitan area surrounding it.

People are growing more and more exacting regarding the quality of the water supplied them, and demand, in addition to being safe, that the water should be clean and free at all times from color, odor or turbidity. It seems certain, then, that in the not distant future all surface water supplies must be filtered before delivery to the consumer.

Respectfully submitted,

J. WALDO SMITH,
Consulting Engineer.

REPORT OF CHIEF ENGINEER.

To the Joint Board on Water Supply Needs and Resources.

Gentlemen: — In accordance with the request of the Joint Board, I present herewith a report upon the water supply needs and resources of the Commonwealth under the provisions of chapter 49 of the Resolves of the year 1919.

Organization and Scope of the Investigation.

In order to make the investigation called for by the resolve it became necessary to create an organization to assist in the work. The difficulty in securing a force of engineers of sufficient experience, together with other unfavorable conditions, was the cause of considerable delay at the beginning, and little was accomplished until 1920, when the full appropriation became available.

Mr. Bertram Brewer, for many years city engineer, and latterly also superintendent of water works, of Waltham was engaged as principal assistant engineer in general charge of the work. Mr. Karl R. Kennison, an engineer of experience in the design of hydraulic works of great importance, was engaged to prepare the designs for the larger structures, while Mr. Arthur D. Weston, Mr. N. LeRoy Hammond and Mr. Francis H. Kingsbury have also been employed in special investigations or in charge of surveying in the field or of major calculations and estimates in the office, while Mr. John S. Hodgson was engaged to make some special financial investigations. Messrs. George R. Hulme, Elmer C. Houdlette and Forrest F. Harbour were in charge of field parties.

Mr. F. P. Stearns, consulting engineer at the time the work was begun, died on December 1, 1919, before much had been accomplished, to the great regret of his associates and the irreparable loss of the State.

Mr. J. Waldo Smith, chief engineer of the New York Water Supply Board since the beginning of construction, was later appointed consulting engineer, and he has followed the investigations and advised freely from time to time as they have progressed.

Prof. William O. Crosby, geologist, has made a comprehensive report on the geology of the Swift River valley, and Dr. Charles P. Berkey of the department of geology of Columbia University has given valuable advice concerning the investigations for and the location of dam sites.

Mr. Charles T. Main, consulting engineer, has advised as to the estimates of water damages, and Mr. H. W. Clark, chemist in charge of the Lawrence Experiment Station of the Department of Public Health, and Director of the Division of Water and Sewage Laboratories, has advised as to filtration problems.

The language of the resolve directing the inquiry is very broad, and, strictly interpreted, includes the investigation of water supply needs and resources of all the cities and towns of the State. On account of the limited funds provided for the purpose, however, the investigation has necessarily been restricted to those cities, towns and districts which are already provided with public water supplies, and especially to those in which the need of additional supply is greatest at the present time.

Growth of Population in Massachusetts.

The growth of population in Massachusetts has been continuous since census enumerations were first made, but in the years that have passed since the beginning of the general introduction of public water supplies, a date which is fixed approximately by the introduction of water from Lake Cochituate into the city of Boston in 1848, the population of the cities and larger towns has increased more rapidly than that of the State as a whole, while the rural population has steadily declined. In 1920, of the 354 cities and towns of the State, 216, or 61 per cent of the total number, were provided with public water supplies in the whole or in a part of their territory, but these 216 municipalities contained 96 per cent of the total population of the State.

It has been assumed for the purposes of this report that the population of the various municipalities considered will continue to increase in the future about as indicated by past experience though at a diminishing rate. The population of the larger municipalities of the State has been increasing constantly for many years, and there is no present indication that a limit is being approached. There has been, to be sure, a reduction in the rate of growth of the population during the recent census period in many cities and towns, and in some a great acceleration, but these were temporary conditions brought about by the war and have been common to most States and countries; but with the close of the war the growth in population will no doubt return to its normal rate.

General Increase in Water Supply Requirements.

It has also been assumed that the quantity of water required for each unit of the population will continue to increase slowly in the future, as indicated by records of water consumption in the past, which are available in most of the cities and towns for long periods of years. These records show that, while the quantity of water used per individual of the total population may vary considerably from time to time in a given municipality with the varying effectiveness of efforts to prevent unnecessary use and waste, with business and industrial activity, and with variations in the character of the seasons, this quantity has been, on the whole, a constantly increasing one. This increase is no doubt due largely to gradually improving standards of living in American municipalities, and to increasing demands for water for business and industrial uses, and its limit cannot be foreseen.

These assumptions as to growth of population and increase in water supply requirements will doubtless vary more or less from the facts as ultimately disclosed, but they appear to furnish the most reliable basis available for estimating the probable requirements of the various municipalities in the matter of water supply, the adequacy of present sources of supply, and the availability of sources capable of development for the use of a given municipality or district.

THE METROPOLITAN DISTRICT.

PART I. WATER SUPPLY REQUIREMENTS.

Municipalities in the Metropolitan Water District.

The Metropolitan Water District was created by chapter 488 of the Acts of the year 1895. It includes at the present time the city of Boston and eighteen suburban cities and towns, as follows: — Arlington, Belmont, Chelsea, Everett, Lexington, Malden, Medford, Melrose, Milton, Nahant, Newton, Quincy, Revere, Somerville, Stoneham, Swampscott, Watertown and Winthrop.

Growth of Population in the Metropolitan Water District.

The total population of the Metropolitan Water District by the census of 1920 was 1,252,903, of which number 748,060 were included in the city of Boston and 504,843 in the suburban cities and towns. Save for the period of the recent war with Germany, the increase in population in thirty-year periods, ending with the census years since 1880, has ranged from 104 to 124 per cent; in other words, excepting in the period of the recent war, the population of the district has more than doubled in each thirty years. In the period of the recent war the increase in population was materially less than formerly, but the same was true of New York and many other communities, and no doubt represents a temporary condition such as prevailed in many places from 1861 to 1865 and which passed with the close of the Civil War.

In estimating the future population of the Metropolitan Water District for the purpose of determining its needs in the matter of water supply it has been assumed that the rate of growth will be less in the future than has been the case in the past. Including the war period from 1915 to 1920, the population of the district about doubled in number in the last thirty-two years. In estimating the future population of the district, it has been assumed that the rate of increase will be about two-thirds as great; that is, it has been assumed that in the future it will require about fifty years for the population to become double what it is to-day. On this assumption the percentage of growth would decrease rapidly in the future, as is shown by the following table and diagram, which give the actual percentage of increase in the population of the district in thirty-year periods prior to 1920, combined with the estimated percentages of increase in similar periods from 1920 to 1970.

Table showing Percentage of Population Increase by Thirty-year Periods, with Estimates for 1920 to 1970.

METROPOLITAN DISTRICT, INCLUDING NEWTON.

Actual.		Estimated.	
1850–1880	123.6	1895–1925	81.2
1855–1885	103.6	1900–1930	73.0
1860–1890	109.6	1905–1935	73.6
1865–1895	123.3	1910–1940	66.8
1870–1900	124.2	1915–1945	59.8
1875–1905	103.5	1920–1950	63.8
1880–1910	113.7	1925–1955	58.0
1885–1915	115.9	1930–1960	52.9
1890–1920	89.1	1935–1965	48.8
		1940–1970	45.1

Upon the basis of the past growth in population, and with the allowance indicated above for a lesser rate of growth in the future, the following table has been prepared, showing the actual population of the district from census records from 1850 to 1920, and the estimated population in each census year from 1920 to 1970.

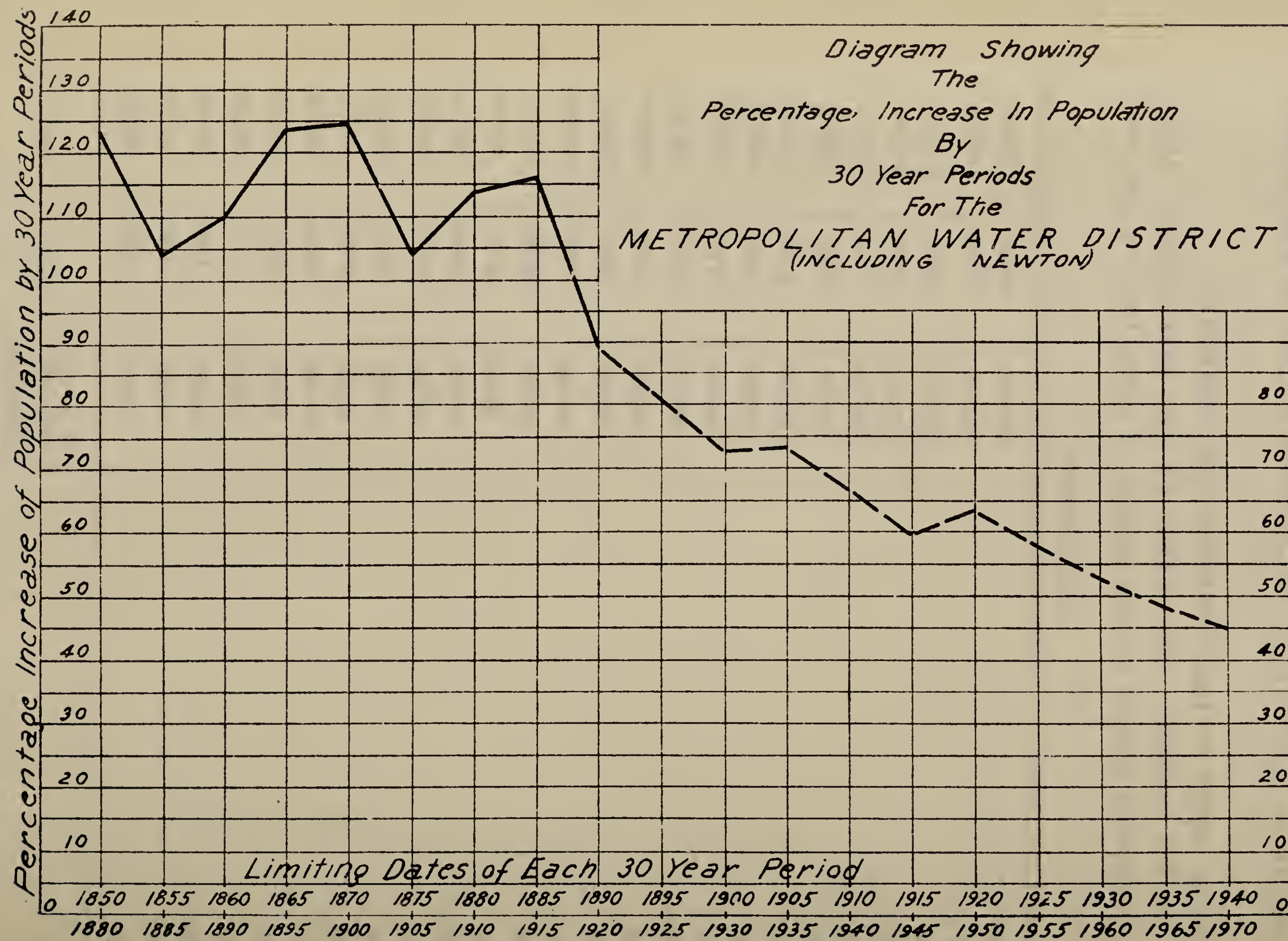


Diagram Showing
The
Percentage Increase In Population
By
30 Year Periods
For The
METROPOLITAN WATER DISTRICT
(INCLUDING NEWTON)
Percentage Increase of Population by 30 Year Periods
Limiting Dates of Each 30 Year Period
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900 1905 1910 1915 1920 1925 1930 1935 1940
1880 1885 1890 1895 1900 1905 1910 1915 1920 1925 1930 1935 1940 1945 1950 1955 1960 1965 1970

Table showing Population of Metropolitan Water District, 1850–1970.

	Metropolitan Water District, excluding Newton.	Newton.	Total.
1850	218,766	5,258	224,024
1855	266,531	6,768	273,299
1860	307,661	8,382	316,043
1865	333,089	8,975	342,064
1870	378,650	12,825	391,475
1875	451,399	16,105	467,504
1880	483,832	16,995	500,827
1885	536,566	19,759	556,325
1890	638,053	24,379	662,432
1895	735,827	27,590	763,417
1900	843,953	33,587	877,540
1905	914,614	36,827	951,441
1910	1,030,450	39,806	1,070,256
1915	1,158,187	43,113	1,201,300
1920	1,206,849	46,054	1,252,903
1925[1]	1,333,680	50,200	1,383,880
1930	1,463,870	54,500	1,518,370
1935	1,592,460	58,900	1,651,360
1940	1,721,550	63,200	1,784,750
1945	1,851,730	67,600	1,919,330
1950	1,979,870	71,800	2,051,670
1955	2,111,080	76,000	2,187,080
1960	2,241,270	80,300	2,321,570
1965	2,373,500	84,500	2,458,000
1970	2,501,170	88,800	2,589,970

[1] 1925–70 estimated.

The above figures do not include a small part of the town of Saugus supplied with water by the Metropolitan Water District, which in 1920 contained 280 inhabitants.

Increase in Water Consumption per Capita in the Metropolitan Water District.

The total quantity of water used for the supply of the Metropolitan Water District in the year 1920, including the city of Newton, was 130,952,000 gallons per day. Excluding the city of Newton, which provided its entire water supply during the year from its own sources, the quantity of water used by the district in 1920 was 127,265,000 gallons per day, or 105.5 gallons to each inhabitant.

There have been great variations in the consumption of water in the municipalities now comprising the Metropolitan District since water supplies were first introduced. The aggregate amount of water used in these municipalities, excluding Newton, in the year 1894, the year before the district was established, was 63,759,000 gallons per day, or 89 gallons per inhabitant; that is, the quantity of water used in that year was about one-half the amount required for the water supply of the district in 1920. Beginning in 1895 with the establishment of the Metropolitan Water District, the consumption of water per inhabitant rose rapidly until 1904, when the more liberal use of meters was begun and the practice soon became general. The consumption of water per capita still remained high for several years, however, reaching 128.4 gallons in 1908, when 22 per cent of the services had been metered; but following legislation in the previous year, requiring the use of meters on all services, the general introduction of meters throughout the district proceeded rapidly until the year 1915, when 67 per cent of all the services in the district had been metered and the consumption of water per capita had fallen to 88 gallons per day, the latter amount being slightly less than the quantity used in the same municipalities in 1894.

This great and rapid reduction in the use of water per capita by means of the general application of meters appeared to solve the problem of waste prevention, a subject which has engaged the serious attention of water works authorities since water works were first introduced; but following the comparatively small quantity of water used in 1915, which was no doubt due to a combination of causes all operating to produce a minimum use of water, the consumption of water per capita again began to increase, and in 1920 had risen to 105.5 gallons per day, notwithstanding the fact that the percentage of metered services had risen in this period from 67 to 75. In one of these years — 1918 — the quantity of water used per capita rose to 109.3 gallons in consequence of an unusually cold winter.

The conditions described have been general throughout the district. In the city of Boston the percentage of metered services is less than in the district as a whole, while in the district exclusive of the city of Boston the proportion of metered services is greater; but the experience has been practically the same in each, viz., a great rise in the consumption of water per capita following the creation of the district, and a great reduction during the general introduction of meters, which continued until about two-thirds of the services had been metered, when the consumption per capita again began to rise, though the percentage of metered services was still increasing. The variations in the daily consumption of water, the consumption of water per capita and the per cent of metered services, so far as available, are shown in the following tables and diagram: —

Average Daily Water Consumption, Metropolitan Water District.

Year.	Metropolitan Water District.	Newton.	Total.
1893	64,795,000	1,370,000	66,165,000
1894	63,759,000	1,623,000	65,382,000
1895	67,698,000	1,801,000	69,499,000
1896	76,548,000	1,812,000	78,360,000
1897	78,989,000	1,804,000	80,793,000
1898	81,893,000	1,758,000	83,651,000
1899	90,075,000	2,036,000	92,111,000
1900	95,973,000	2,086,000	98,059,000
1901	102,802,000	1,843,000	104,645,000
1902	108,418,000	1,927,000	110,345,000
1903	108,168,000	2,109,000	110,277,000
1904	114,937,000	2,188,000	117,125,000
1905	117,757,000	2,151,000	119,908,000
1906	118,567,000	2,223,000	120,790,000
1907	125,307,000	2,318,000	127,625,000
1908	126,479,000	2,444,000	128,923,000
1909	120,240,000	2,344,000	122,584,000
1910	113,239,000	2,505,000	115,744,000
1911	110,907,000	2,583,000	113,490,000
1912	116,231,000	2,732,000	118,963,000
1913	103,848,000	2,889,000	106,737,000
1914	107,036,000	2,960,000	109,996,000
1915	101,942,000	2,830,000	104,772,000
1916	106,338,000	3,099,000	109,437,000
1917	110,032,000	3,121,000	113,153,000
1918	129,764,000	3,426,000	133,190,000
1919	120,594,000	3,488,000	124,082,000
1920	127,265,000	3,687,000	130,952,000

Records from 1893–1903, inclusive, based on pumpage records.

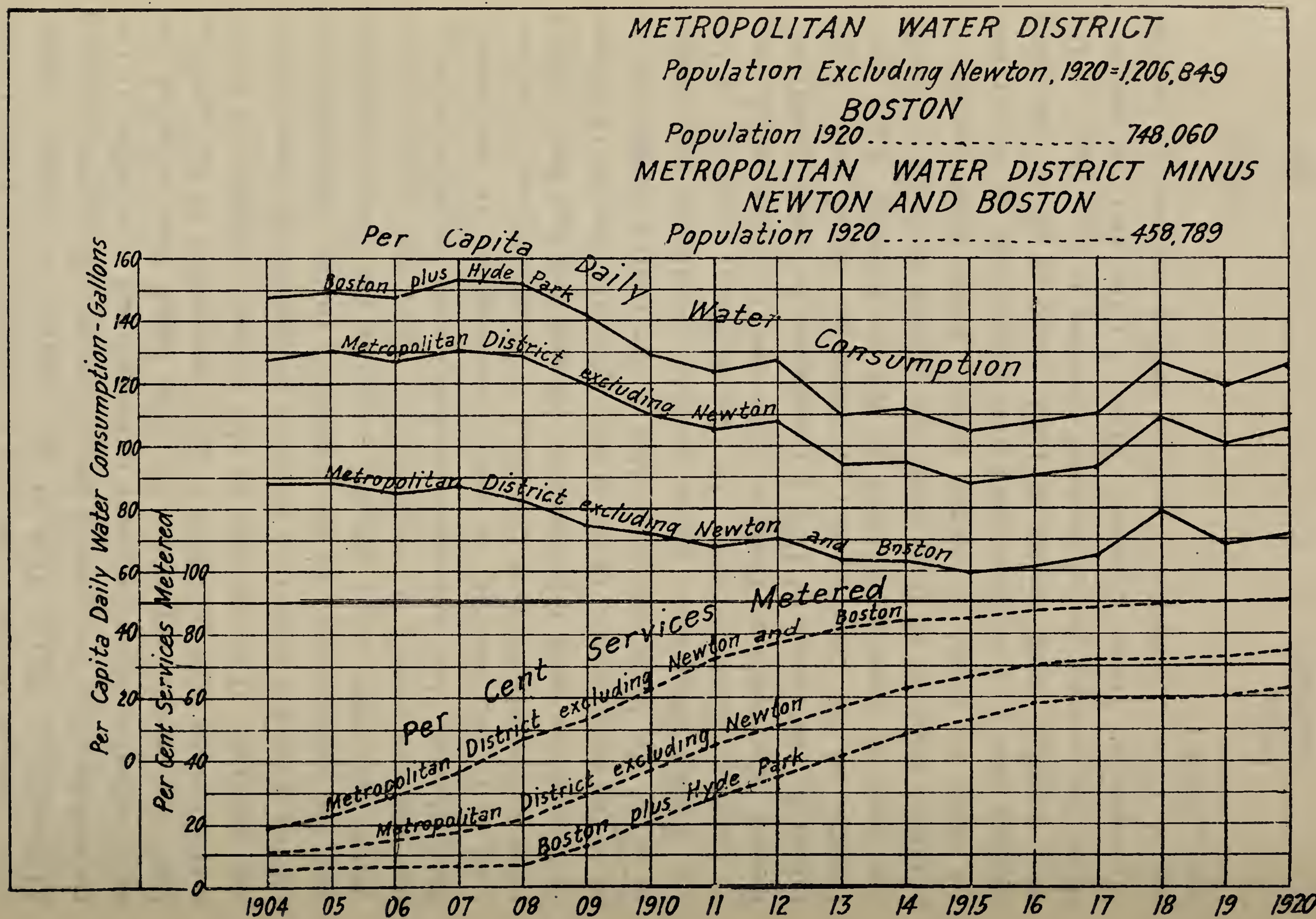
Records from 1904 to date, inclusive, based on meter records.

Records from 1893–1908, inclusive, include small amount of water supplied by Revere to Saugus (this amount not included after 1908).

Table showing Population, Per Capita Daily Consumption and Per Cent of Metered Services in Boston and the Metropolitan Water District.

	Metropolitan Water District.						Boston.			Metropolitan District Minus Boston.					
	Including Newton.			Excluding Newton.						Including Newton.			Excluding Newton.		
	Population.	Per Cent Metered.	Per Capita Consumption (Gallons).	Population.	Per Cent Metered.	Per Capita Consumption (Gallons).	Population.	Per Cent Metered.	Per Capita Consumption (Gallons).	Population.	Per Cent Metered.	Per Capita Consumption (Gallons).	Population.	Per Cent Metered.	Per Capita Consumption (Gallons).
1904	936,861	14.4	125.0	900,682	10.8	127.6	602,739	5.9	147.2	334,122	27.0	85.1	297,943	19.0	88.1
1905	951,641	16.0	126.2	914,814	12.5	128.8	609,890	6.1	149.0	341,751	30.5	85.0	304,924	23.0	88.2
1906	975,434	18.5	123.9	938,011	15.1	126.5	625,130	6.3	147.2	350,304	36.2	82.2	312,881	29.5	84.9
1907	999,237	21.0	127.7	961,218	17.7	130.4	640,371	6.4	152.4	358,866	42.1	83.7	320,847	36.2	86.4
1908	1,023,010	24.9	126.0	984,396	21.8	128.4	655,611	6.5	151.6	367,399	52.4	80.3	328,785	47.6	82.3
1909[1]	1,046,493	31.4	117.1	1,007,283	28.6	119.3	670,852	12.9	141.8	375,641	57.3	73.1	336,431	53.4	74.5
1910	1,070,256	40.0	108.2	1,030,450	37.5	109.9	686,092	20.7	129.0	384,164	66.7	71.0	344,358	63.8	71.9
1911	1,096,466	47.7	103.5	1,055,999	45.5	105.0	697,962	28.1	123.9	398,504	74.4	67.8	358,037	72.3	68.2
1912	1,122,675	53.7	106.0	1,081,546	51.7	107.5	709,831	34.8	126.8	412,844	79.1	70.4	371,715	77.5	70.5
1913	1,148,881	59.2	92.8	1,107,091	57.6	93.9	721,700	41.4	110.0	427,181	82.7	64.1	385,391	81.7	63.5
1914	1,175,091	63.9	93.6	1,132,639	62.5	94.6	733,570	47.4	111.6	441,521	85.2	63.7	399,069	84.5	63.0
1915	1,201,300	67.8	87.2	1,158,187	66.6	88.0	745,439	53.1	104.2	455,861	86.3	59.5	412,748	85.7	58.8
1916	1,211,618	71.8	90.4	1,167,917	70.8	91.1	745,936	58.3	107.7	465,682	88.6	62.4	421,981	87.9	61.6
1917	1,221,941	73.3	92.6	1,177,652	72.2	93.5	746,433	59.9	110.0	475,508	89.8	65.4	431,219	89.0	64.9
1918	1,232,261	73.6	108.1	1,187,383	72.4	109.3	746,929	59.9	126.7	485,332	90.3	79.5	440,454	89.5	79.8
1919	1,242,586	74.4	99.8	1,197,120	73.3	100.7	747,426	60.5	119.9	495,160	91.1	69.5	449,694	90.4	68.8
1920	1,252,903	75.6	104.5	1,206,849	74.6	105.5	748,060	62.5	126.0	504,843	91.3	72.6	458,789	91.1	71.9

[1] Prior to 1909 the water consumption of Revere includes that of a small part of Saugus, and consequently prior to that year the estimated population of the part of Saugus supplied has been added, which amounts to from 200 to 280 persons.


METROPOLITAN WATER DISTRICT
Population Excluding Newton, 1920=1,206,849
BOSTON
Population 1920 748,060
METROPOLITAN WATER DISTRICT MINUS
NEWTON AND BOSTON
Population 1920 458,789
Per Capita Daily Water Consumption
Boston plus Hyde Park
Metropolitan District excluding Newton
Metropolitan District excluding Newton and Boston
Per Cent Services Metered
Metropolitan District excluding Newton and Boston
Metropolitan District excluding Newton
Boston plus Hyde Park
Per Capita Daily Water Consumption - Gallons
160
140
120
100
80
60
40
20
0
Per Cent Services Metered
100
80
60
40
20
0
1904
05
06
07
08
09
1910
11
12
13
14
1915
16
17
18
19
1920

Increase in per Capita Consumption of Water in Large Northern Cities.

In view of the fact that the consumption of water in the Metropolitan Water District has begun to increase again, notwithstanding the general use of meters, the question arises as to whether this experience is exceptional or whether it has been the general experience in cities which have adopted the meter system and in which a large proportion of the services are metered. The practice of the general metering of water service pipes has come into vogue in comparatively recent years, and the experience as to the variations in the consumption of water per capita after general metering has been established has been necessarily a comparatively short one in most cases. Nevertheless, this experience furnishes most valuable information as to the tendency in water consumption at the present time, and especially as to the effect of the general use of meters. In connection with this question, information has been sought as to the consumption of water per capita and the use of meters in all of the large northern cities of the United States east of the Rocky Mountains where climatic conditions are similar to those in Massachusetts. In this territory, exclusive of the Boston Metropolitan District, there are 13 cities which contained by the census of 1920 a population in excess of 400,000. Records of the consumption of water per capita and of the per cent of metered services so far as available have been obtained from all of these cities for periods covering in nearly all cases as many as thirty years. From these records it appears that in 5 of these cities over 90 per cent of the services were supplied with meters in 1920, while in all of the other cities the percentage of metered services is less than in the Metropolitan Water District. These 5 cities and the percentage of services metered in each in 1920 are shown in the following table: —

	Per Cent.
Detroit	97
Cincinnati	99
Cleveland	100
Milwaukee	99
Newark	92

Effect of High Percentage of Metered Services in the Largest Cities.

In Detroit there had been a few metered services for many years, the number rising to about 13 per cent in 1914 and to 24 per cent in 1915. In the following three years meters were applied rapidly, the number rising to 96 per cent in 1919. In this period the consumption of water per capita fell from 169 gallons in 1915 to 129 gallons in 1919, rising in 1920 to 144 gallons.

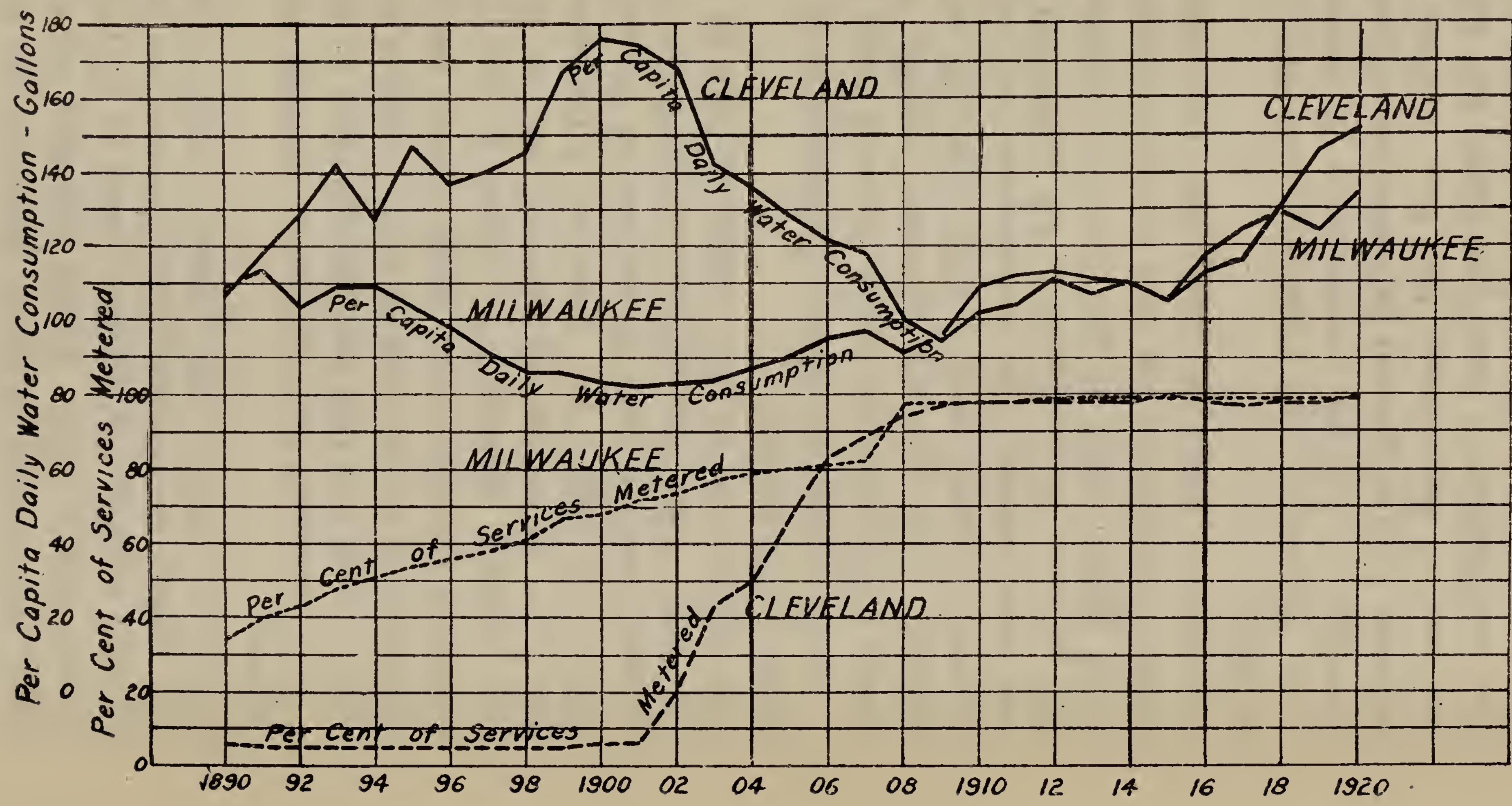
In Cincinnati the number of metered services was low for many years, but this number had risen to about 21 per cent in 1908 and to 33 per cent in 1910. Meters were applied rapidly following the latter year until in 1917 the percentage of services metered amounted to about 71 per cent, or a little less than the percentage of metered services in the Metropolitan District in 1920. The metering of the service pipes was continued, however, until 99 per cent of the services were metered by 1920. The consumption of water per capita in 1917 was 132 gallons, the amount falling in 1919 to 130 gallons and in 1920 to 123 gallons.

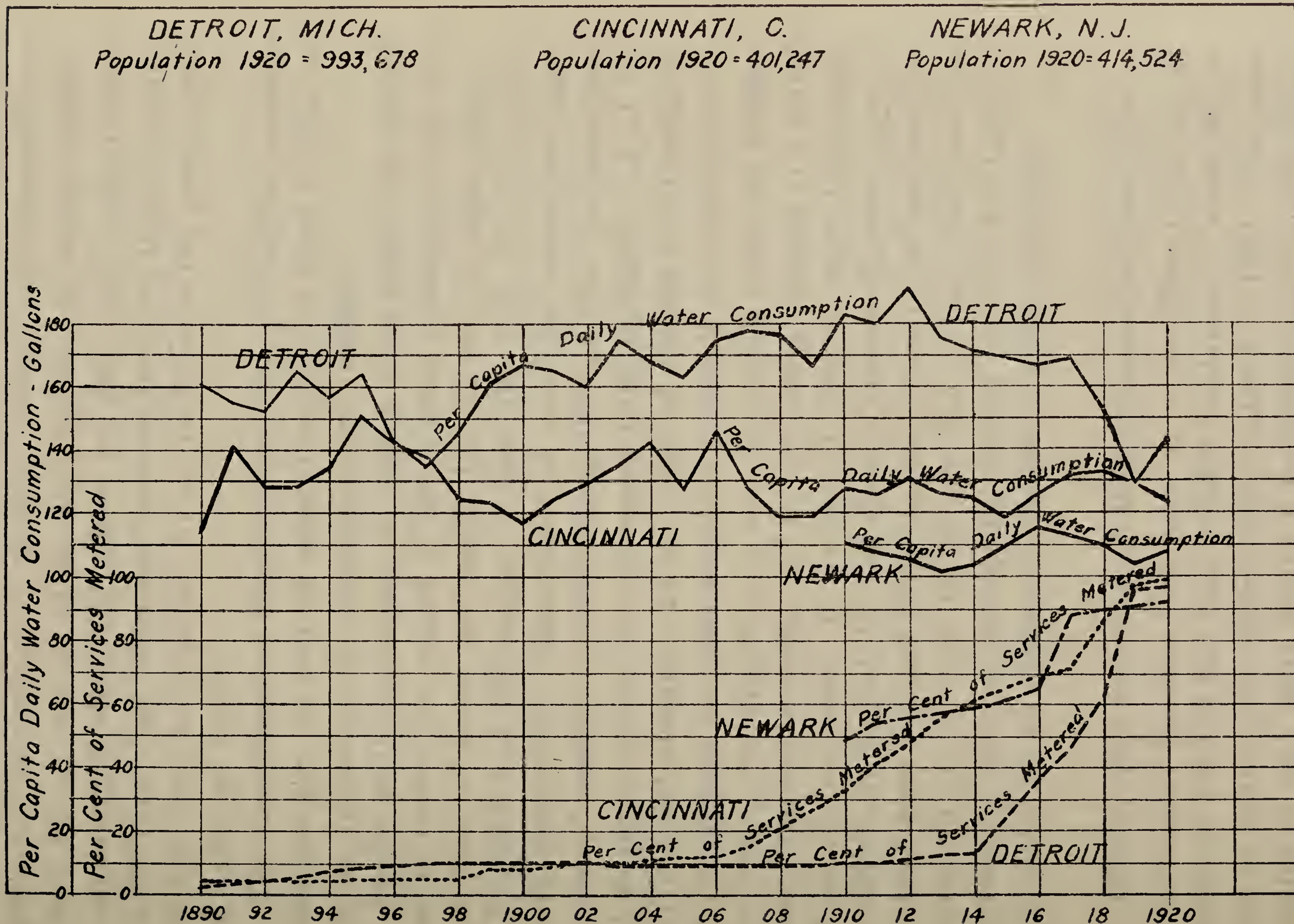
In Cleveland the general introduction of meters was begun about 1902, when the consumption of water per capita was 168 gallons. This amount decreased rapidly as the number of meters increased, until in 1905, when 68 per cent of the services were metered, the consumption per capita had fallen to 128 gallons. It continued to fall until 1909, when it amounted to 94 gallons, with 97 per cent of the services metered. Since 1909, with over 97 per cent of the services metered, the consumption of water per capita has risen from 94 to 152 gallons in 1920.

In Milwaukee the experience has been similar to that of Cleveland. A high consumption of water per capita was reduced by the general introduction of meters, and when 72 per cent of the services had been metered in the year 1901 the consumption of water per capita had fallen in the previous ten years from a maximum of 113 gallons to a minimum of 82 gallons. Since 1901 the consumption per capita has risen, notwithstanding the practically complete metering of all the services in the city, reaching a maximum of 134 gallons in 1920.

CLEVELAND, O.
Population 1920 = 796,841

MILWAUKEE, WIS.
Population 1920 = 457,147




DETROIT, MICH.
Population 1920 = 993,678
CINCINNATI, O.
Population 1920 = 401,247
NEWARK, N.J.
Population 1920 = 414,524
Per Capita Daily Water Consumption - Gallons
Per Cent of Services Metered
DETROIT
Per Capita Daily Water Consumption
CINCINNATI
Per Capita Daily Water Consumption
NEWARK
Per Capita Daily Water Consumption
NEWARK Per Cent of Services Metered
CINCINNATI
Per Cent of Services Metered
Per Cent of Services Metered
DETROIT
1890
92
94
96
98
1900
02
04
06
08
1910
12
14
16
18
1920

In Newark, N. J., in the years 1912, 1913 and 1914, with 56 to 59 per cent of the services metered, the average per capita consumption was 104 gallons per day. In 1918, 1919 and 1920, when the percentage of metered services had increased from 90 to 92 per cent of all the services, the per capita consumption averaged about 107 gallons per day; that is, the increase in the percentage of metered services from less than 60 to over 90 had been accompanied by an increase in the consumption of water per capita.

The accompanying diagrams show the per capita consumption and the per cent of metered services in these 5 cities, so far as the records of consumption are available.

So far as the experience of these 5 cities shows, the general use of meters has caused at first a great reduction in the consumption of water per capita, but in two of these cities, — Cleveland and Milwaukee, — since the bulk of the services were metered the consumption of water per capita has again increased rapidly, notwithstanding the fact that the percentage of metered services has increased until practically all of the services are metered. In the cities of Detroit and Cincinnati the experience has been too short to enable safe conclusions to be drawn, the experience in one case having shown an increase since complete metering, and in the other a decrease in a period of one or two years. In the case of Newark, where the records available are limited, the full effect of the use of meters appears to have been obtained when the percentage of metered services amounted to from 55 to 60 per cent. Since that time the increase of metered services to over 90 per cent has been accompanied by an increase in the use of water per capita.

Effect of High Percentage of Metered Services in Other Cities.

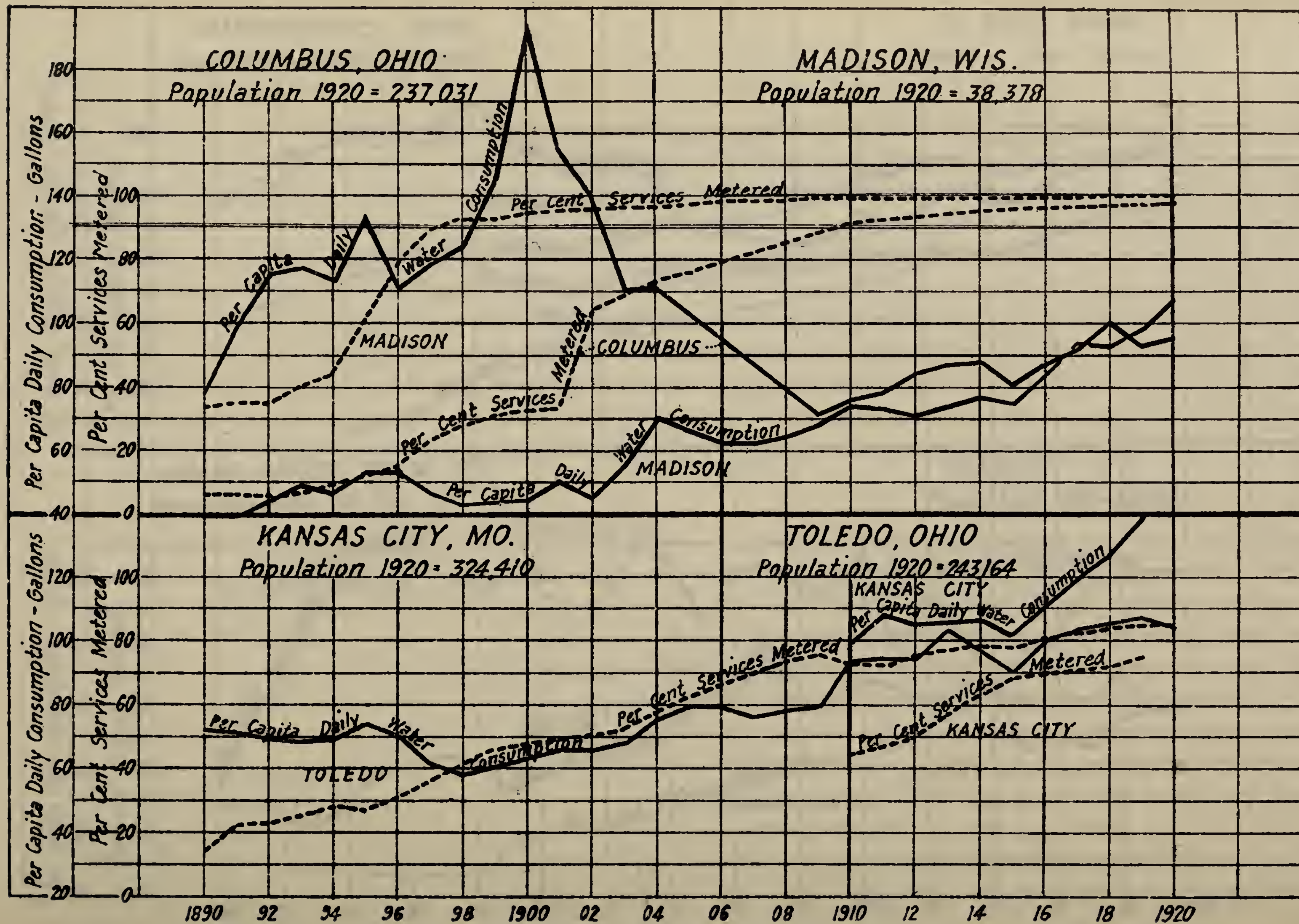
An inquiry has also been made as to the effect of the use of meters in cities of less than 400,000 inhabitants in which 90 per cent or more of the services were metered in 1920. The total number of such cities having a population in excess of 25,000, including 9 in Massachusetts, from which returns have been received, is 19, and in addition there are 3 cities with from 75 to 85 per cent of the services metered in 1919 or 1920. The variations in the use of water per capita in these cities and in the percentage of services metered in the last thirty years, or so far as records are available within that period, are shown in the following diagrams.

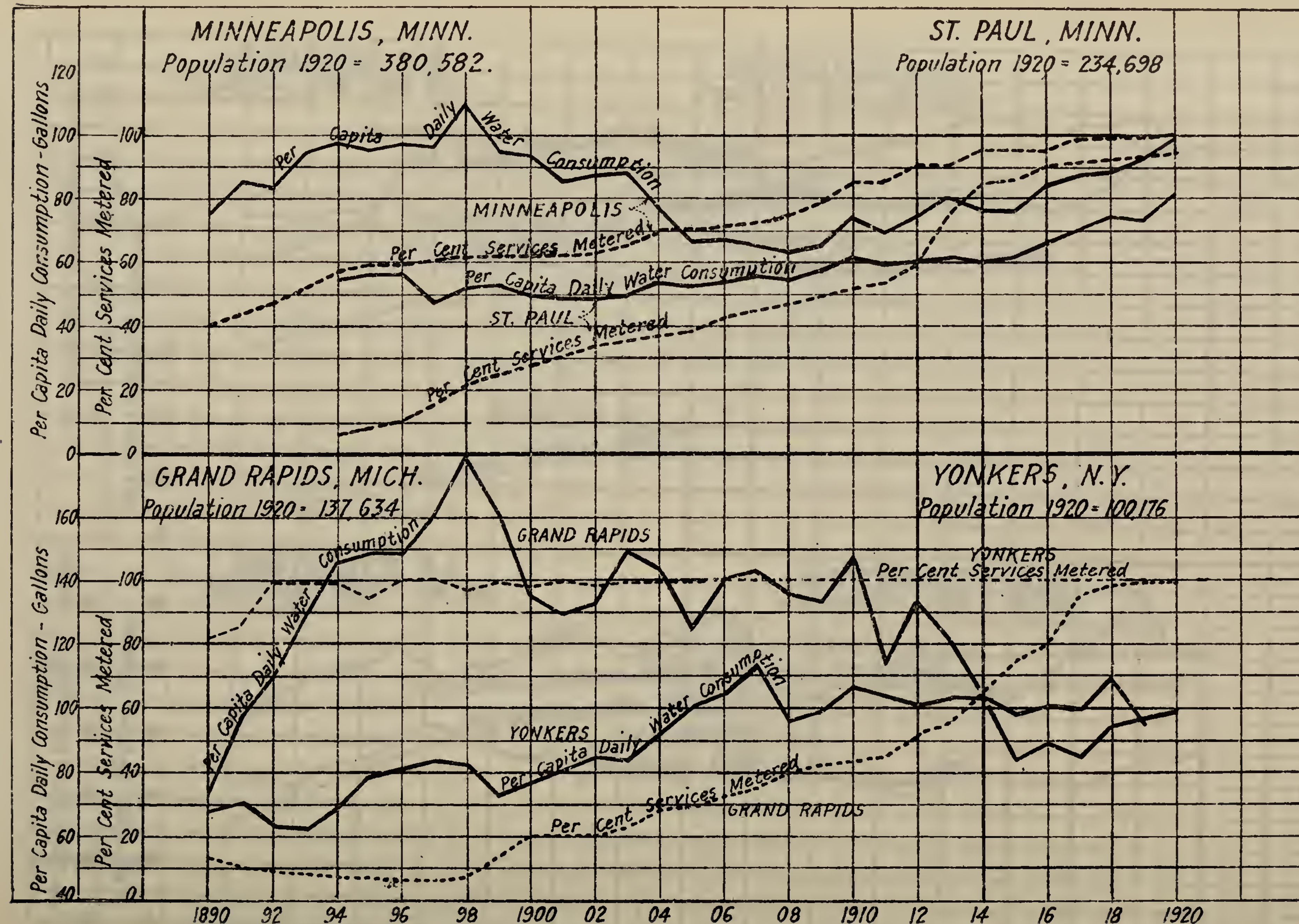
A diagram has also been included showing the consumption per capita and the per cent of metered services in a residential district, comprising Brookline, Newton, Needham, and Wellesley, containing 97,038 inhabitants in 1920, adjacent to the Metropolitan Water District.

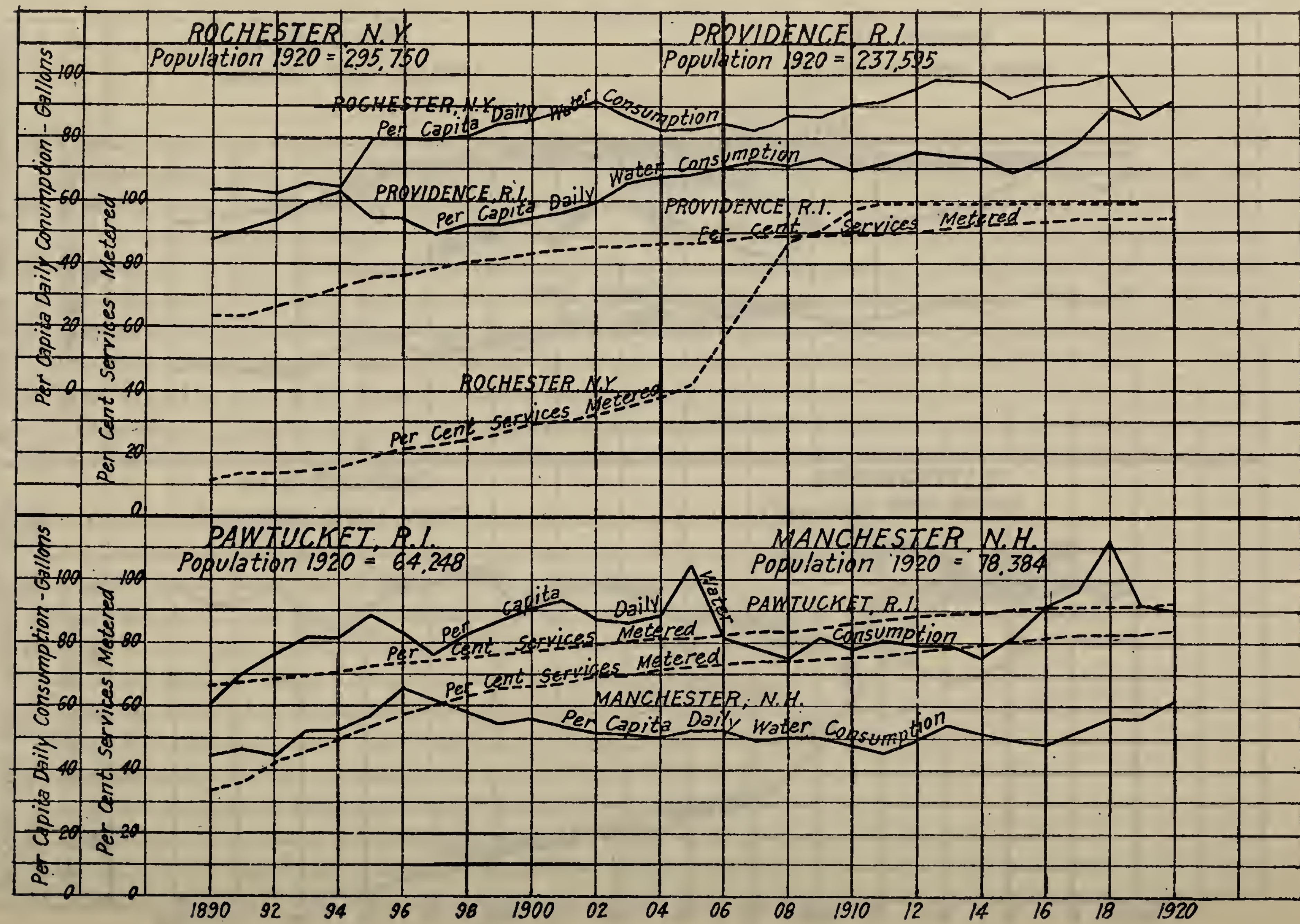
The experience of the different cities following the general metering of all services, as shown in the foregoing diagrams, shows that in a great majority of cases the general introduction of meters in a city where few meters had previously been in use has been followed by a large reduction in the use of water per capita. The experience in the Metropolitan Water District in this respect is duplicated in nearly all of the cities for which records have been obtained. But the diagrams also indicate clearly that in the great majority of the cities from which returns have been secured, after two-thirds or more of the services had been metered the consumption of water per capita began again to increase, and has continued to increase up to the present time, even after most or all of the services have been metered.

General Increase in Daily per Capita Consumption after Two-thirds to Three-fourths of Services had been Metered.

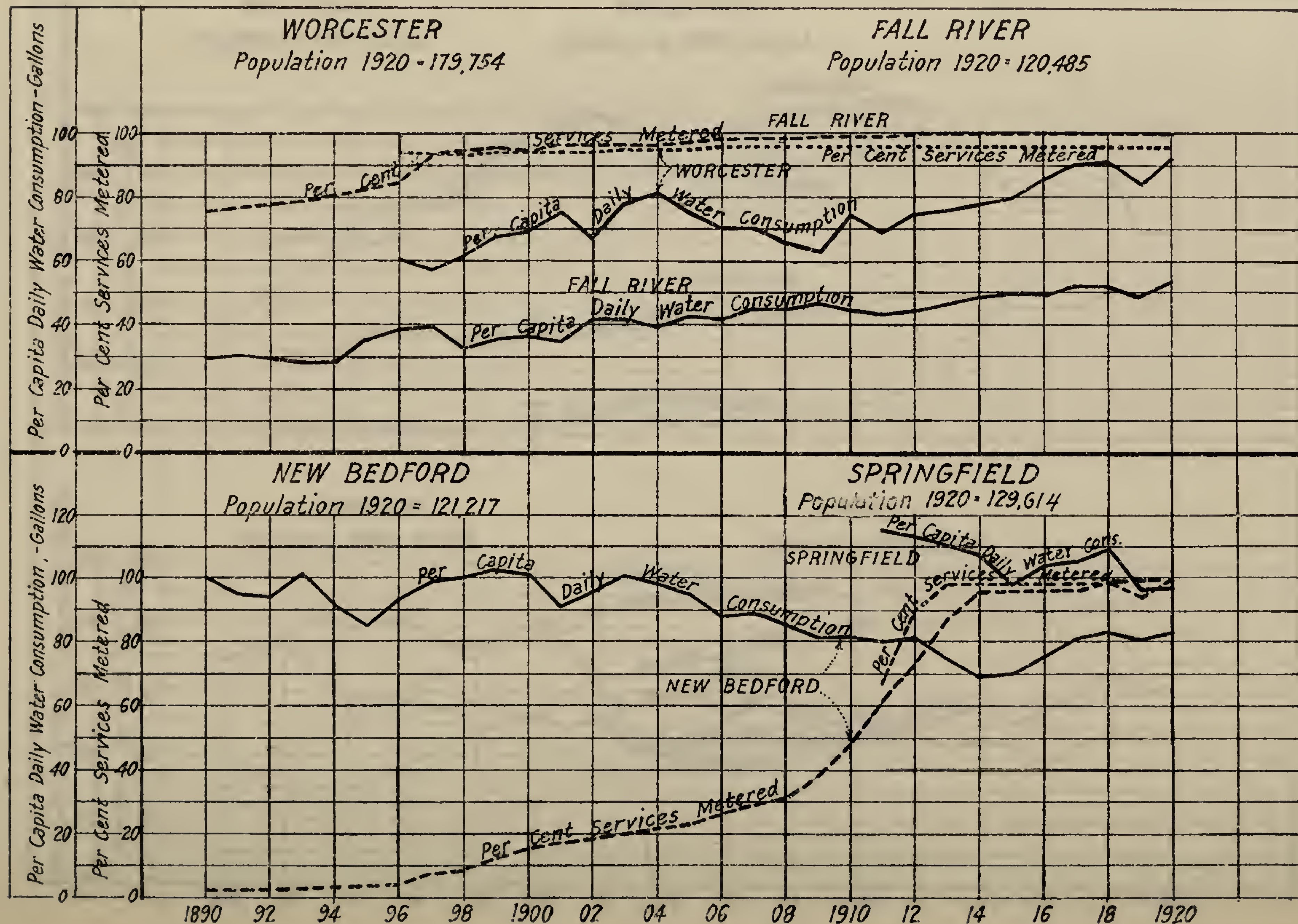
The following table shows the changes in the use of water per capita, after about 75 per cent of the services had been metered, in all of the cities in which the percentage of services metered was substantially greater than 75 per cent in 1920, and in which there has been a sufficient number of years of high percentage of metering to allow comparisons to be made. In this table an average of the three years when about 74 per cent of the services had been metered is compared with an average of the last three years available, usually the years 1918, 1919 and 1920.

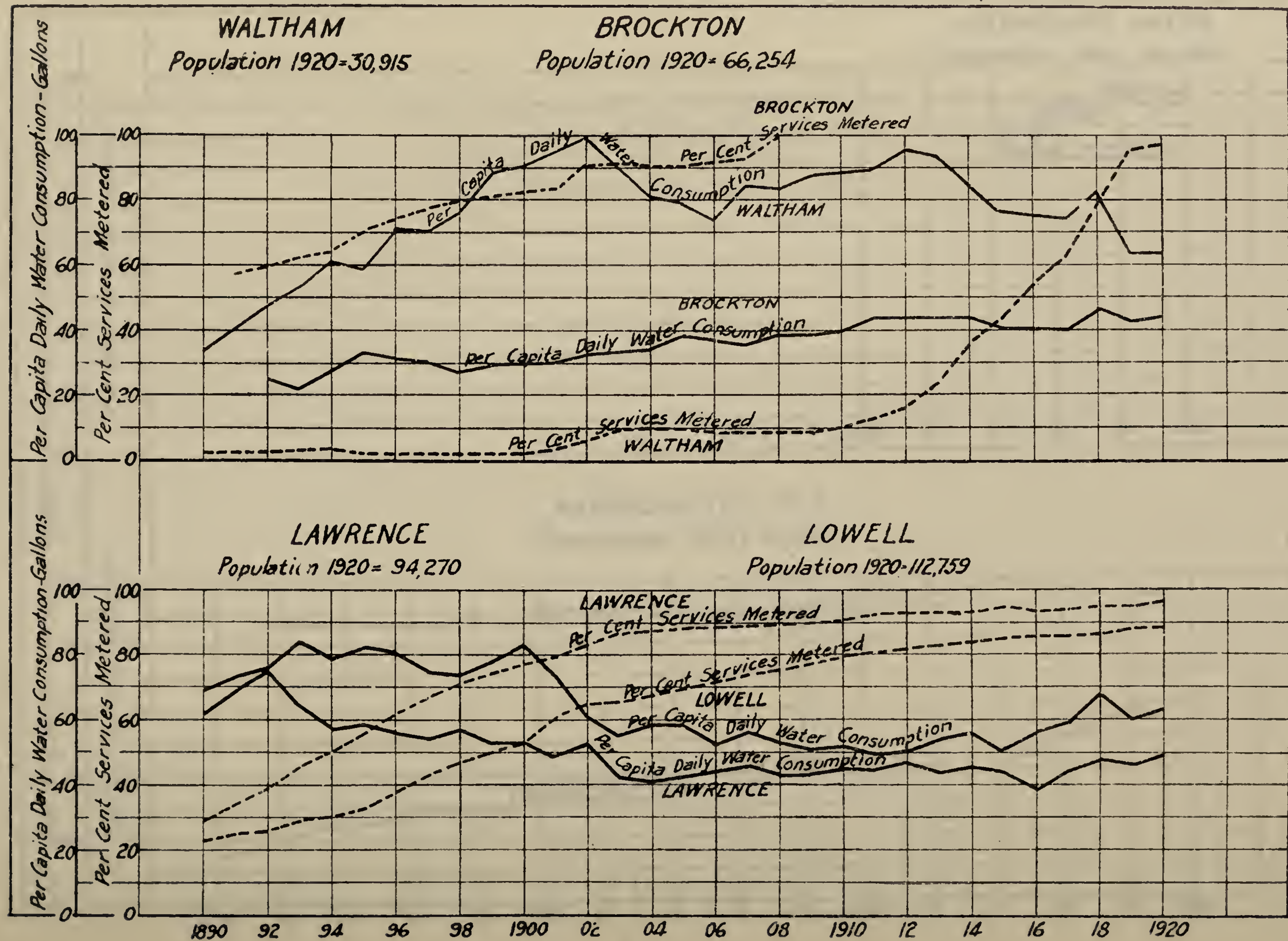

COLUMBUS, OHIO
Population 1920 = 237,031
MADISON, WIS.
Population 1920 = 38,378
KANSAS CITY, MO.
Population 1920 = 324,410
TOLEDO, OHIO
Population 1920 = 243164
Per Capita Daily Consumption - Gallons
Per Cent Services Metered
Per Capita Daily Water Consumption
Per Cent Services Metered
MADISON
COLUMBUS
TOLEDO
KANSAS CITY
Per Cent Services KANSAS CITY
1890 92 94 96 98 1900 02 04 06 08 1910 12 14 16 18 1920

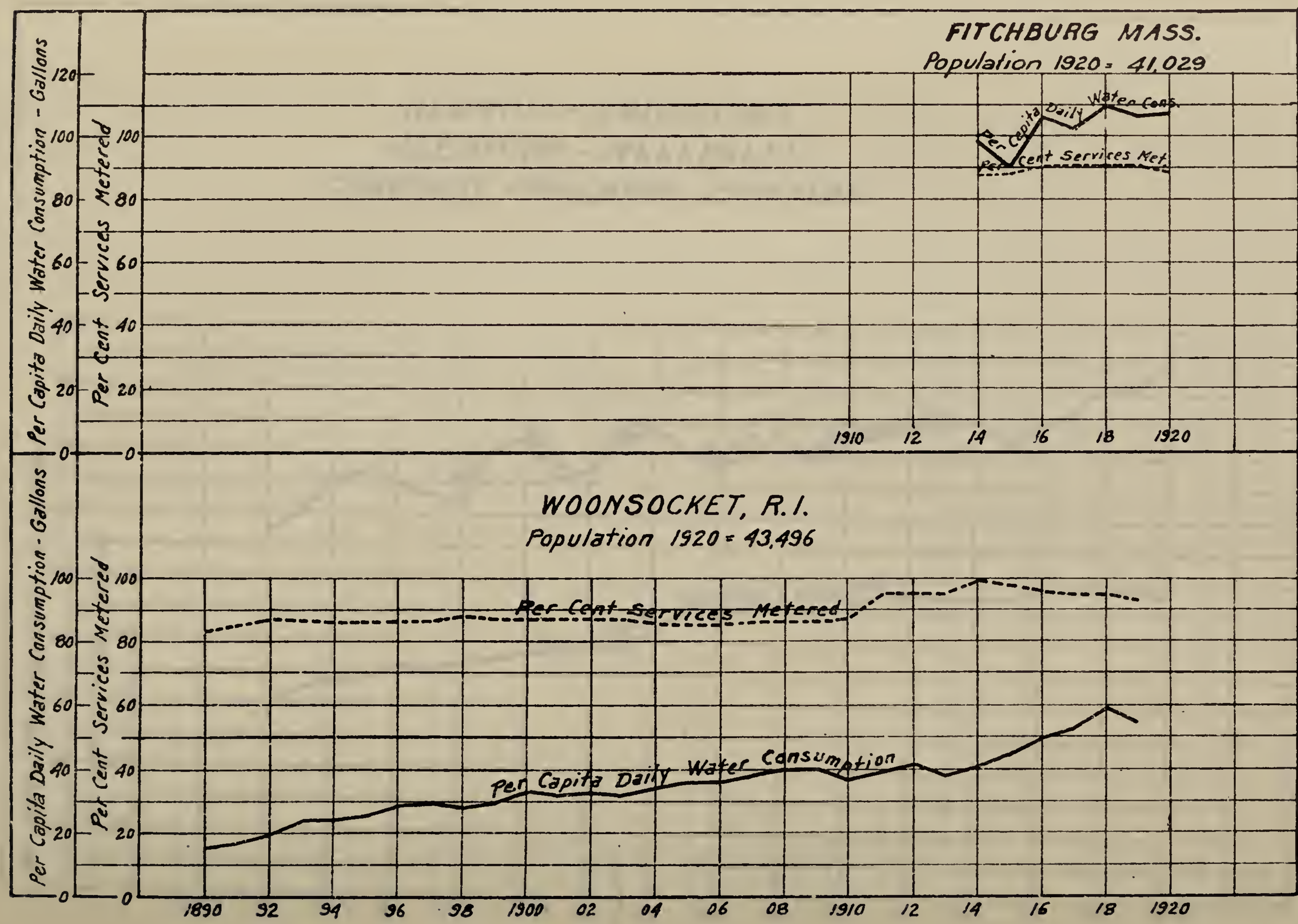

MINNEAPOLIS, MINN.
Population 1920 = 380,582.
ST. PAUL, MINN.
Population 1920 = 234,698
Per Capita Daily Consumption - Gallons
Per Cent Services Metered
Per Capita Daily Water Consumption
MINNEAPOLIS
Per Cent Services Metered
Per Capita Daily Water Consumption
ST. PAUL
Per Cent Services Metered
GRAND RAPIDS, MICH.
Population 1920 = 137,634
YONKERS, N.Y.
Population 1920 = 100,176
Per Capita Daily Water Consumption
GRAND RAPIDS
YONKERS
Per Cent Services Metered
YONKERS
Per Capita Daily Water Consumption
Per Cent Services Metered
GRAND RAPIDS
1890
92
94
96
98
1900
02
04
06
08
1910
12
14
16
18
1920



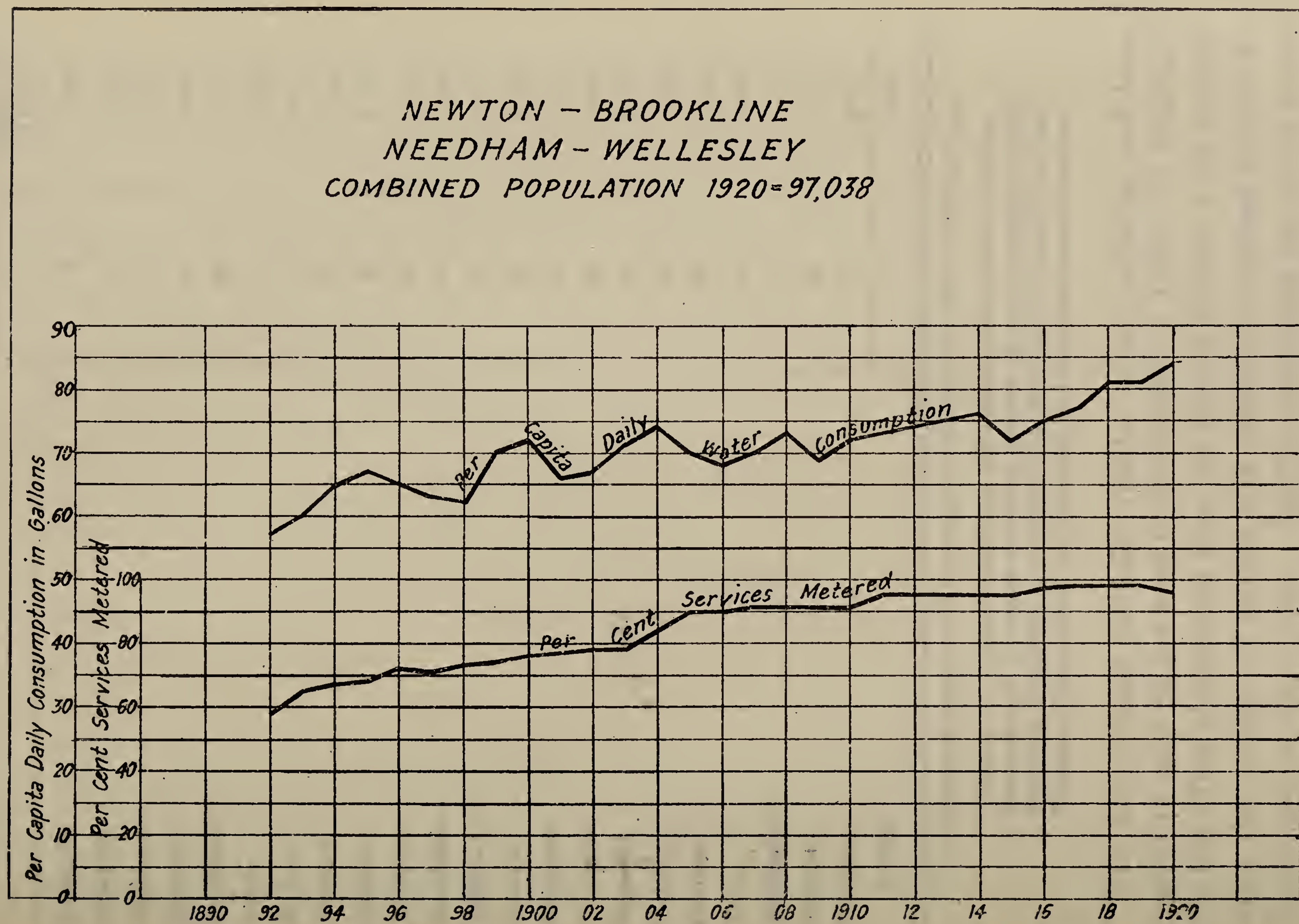
ROCHESTER, N.Y.
Population 1920 = 295,750
PROVIDENCE, R.I.
Population 1920 = 237,595
ROCHESTER, N.Y. Per Capita Daily Water Consumption
PROVIDENCE, R.I. Per Capita Daily Water Consumption
PROVIDENCE, R.I. Per Cent Services Metered
ROCHESTER, N.Y. Per Cent Services Metered
Per Capita Daily Conumption - Gallons
Per Cent Services Metered
PAWTUCKET, R.I.
Population 1920 = 64,248
MANCHESTER, N.H.
Population 1920 = 78,384
PAWTUCKET, R.I. Per Capita Daily Water Consumption
Per Cent Services Metered
Per Cent Services Metered
MANCHESTER, N.H. Per Capita Daily Water Consumption
Per Capita Daily Consumption - Gallons
Per Cent Services Metered
0
20
40
60
80
100
1890
92
94
96
98
1900
02
04
06
08
1910
12
14
16
18
1920


WORCESTER
Population 1920 = 179,754
FALL RIVER
Population 1920 = 120,485
Per Capita Daily Water Consumption - Gallons
Per Cent Services Metered
Per Cent Services Metered
FALL RIVER
Per Cent Services Metered
WORCESTER
Per Capita Daily Water Consumption
FALL RIVER
Per Capita Daily Water Consumption
NEW BEDFORD
Population 1920 = 121,217
SPRINGFIELD
Population 1920 = 129,614
Per Capita Daily Water Consumption, - Gallons
Per Cent Services Metered
Per Capita Daily Water Consumption
Per Capita Daily Water cons.
SPRINGFIELD
Services Metered
Per Cent
NEW BEDFORD
Per Cent Services Metered
1890
92
94
96
98
1900
02
04
06
08
1910
12
14
16
18
1920


WALTHAM
Population 1920=30,915
BROCKTON
Population 1920=66,254
BROCKTON
Services Metered
Per Capita Daily Water Consumption
Per Cent
WALTHAM
BROCKTON
Per Capita Daily Water Consumption
Per Cent Services Metered
WALTHAM
Per Capita Daily Water Consumption-Gallons
Per Cent Services Metered
LAWRENCE
Population 1920=94,270
LOWELL
Population 1920-112,759
LAWRENCE
Per Cent Services Metered
Per Cent Services Metered
LOWELL
Per Capita Daily Water Consumption
Per Capita Daily Water Consumption
LAWRENCE
1890
92
94
96
98
1900
02
04
06
08
1910
12
14
16
18
1920



FITCHBURG MASS.
Population 1920 = 41,029
Per Capita Daily Water Cons.
Per Cent Services Met.
WOONSOCKET, R.I.
Population 1920 = 43,496
Per Cent Services Metered
Per Capita Daily Water Consumption
Per Capita Daily Water Consumption - Gallons
Per Cent Services Metered


NEWTON – BROOKLINE
NEEDHAM – WELLESLEY
COMBINED POPULATION 1920 = 97,038
Per Capita Daily Consumption in Gallons
Per Cent Services Metered
Per Capita Daily Water Consumption
Per Cent Services Metered
0 10 20 30 40 50 60 70 80 90
0 20 40 60 80 100
1890 92 94 96 98 1900 02 04 06 08 1910 12 14 16 18 1920

City.	Years since about 75 Per Cent of the Services became Metered.	Increase or Decrease in Consumption of Water per Capita in Those Years (Gallons per Year).
Cleveland	13	1.59
Milwaukee	17	2.70
Minneapolis	11	2.61
Rochester	11	1.48
Providence	24	1.33
Toledo	11	2.52
St. Paul	6	2.61
Hartford	18	—.50
Yonkers	29	1.15
Pawtucket	22	.79
Manchester	11	.73
Atlantic City	20	3.73
Madison	23	2.12
Burlington	17	1.10
Woonsocket	28	1.42
Worcester	23	1.26
Fall River	29	.80
Lawrence	20	—.32
Lowell	12	.86
New Bedford	7	.57
Brockton	23	.57
Fitchburg	5	2.07
Average	-	1.42[1]

[1] This average would be 1.31 if average of returns for 1917, 1918 and 1919 were used.

Yonkers, N. Y., records used begin 1890 with 82 per cent metered services.
Woonsocket, R. I., records used begin 1890 with 83 per cent metered services.
Fitchburg, Mass., records used begin 1914 with 87 per cent metered services.
Worcester, Mass., records used begin 1896 with 93 per cent metered services.

The above table includes Toledo, where metering had been carried to only 85 per cent of all services in 1920. In Hartford the full effect of metering does not appear to have been secured when the number of meters was suddenly increased from 6 to 71 per cent in three years. Shortly afterwards the use of water decreased, and in the past thirteen years there has been an increase of 0.38 of a gallon per capita per year. The record of water consumption in Harrisburg is very erratic, there having been a very great increase in the use of water while the percentage of meters was rising from some 40 to 80 between the years 1896 and about 1910. Since the latter year the percentage of meters has varied but little, while the consumption per capita has varied quite widely. The percentage of metered services had only reached 86 per cent of the total in 1919. In the last seven years there has been a slight increase in the consumption of water per capita.

Among Massachusetts cities, the consumption of water in the city of Lawrence, after more than 75 per cent of the services were metered in 1900, has decreased in twenty years 0.2 of a gallon per person per year, but since becoming more than 90 per cent metered in 1910 the consumption has increased at the rate of 0.4 of a gallon per year. In Fall River, after the percentage of metered services reached about 75, the increase in the consumption per capita in thirty years was 0.8 of a gallon per person per year. After meters had been applied to more than 90 per cent of the services the increase in twenty-three years was 0.61 of a gallon per year.

Of all this group of cities the important ones which show a decrease in the consumption per capita are Newark, Lawrence and Hartford. The records in Newark are rather short for reliable conclusions, and if these records be omitted the only exceptions to the rule are Hartford and Lawrence, and even in these cases, apparently after the full effect of metering had been experienced, the consumption per capita again increased. In the quite fully metered communities in the Metropolitan District outside of Boston there has been an increase in the consumption of water per capita in the last six years, though as in the other cases this period is too short to furnish a definite basis for estimating the probable amount of increase in the future. In the suburban municipalities of Brookline and Newton, Needham and Wellesley the increase since 70 per cent of the services became metered in the year 1896 has amounted to about 0.8 of a gallon per person per year.

The information afforded by a study of the consumption of water in these cities shows that when 75 per cent or more of the services have been metered, as is the case at the present time in the Metropolitan Water District, practically the full effect of the use of meters has been obtained, and, as a general rule, no further material reduction in the use of water per capita is afterwards secured by the metering of all services. The chief reason for the complete use of meters, aside from the saving in water consumption, is that it is the only equitable way in which to assess the charges for water. This being the case, the application of meters to the remaining service pipes will no doubt be continued in the Metropolitan Water District until the meter system is practically complete.

But while as a general rule no further material reduction in the use of water per capita is effected by the complete metering of all the services after about two-thirds to three-fourths have been metered, it is, nevertheless, true, as shown by a study of the variations in the consumption of water per capita in cities for which records are available, that in some cases a temporary reduction has been effected which has retarded for a few years the increase in consumption per capita. In some of these cities where the meter system was adopted many years ago information is lacking as to the effect of metering the remaining services after a total of 75 per cent or thereabouts had been reached, and in others the complete metering of the services was carried out too recently to furnish definite information in respect to this question, while in still others the application of additional meters after a total of two-thirds to three-fourths of the services had been metered was accompanied by a steady increase in the consumption of water per capita. However, in about one-third of the total number, or in 11 of the cities for which records are available, the application of meters to the remaining services after about two-thirds to three-fourths had been metered caused for a time a reduction in the consumption of water per capita. In these cities the amount of the reduction ranged from 1 to 18 gallons per capita, and averaged 9 gallons in periods ranging from one to fourteen years and averaging 4.5 years. After this period the consumption of water per capita again began to increase and returned to the earlier figure in from two to twelve years, except in the case of one small manufacturing city where the period amounted to twenty-one years. The length of this period of return averaged 8.6 years, or, if the city referred to were excluded, 7.4 years.

The reduction in the consumption per capita as shown in these cases usually followed a much greater previous reduction due to the application of meters up to two-thirds to three-fourths of the total number of services, and was a continuation of that reduction. There is no case in which the consumption of water has been subsequently reduced after it had begun to increase when two-thirds to three-fourths of all the services had been metered, as in the case of the Metropolitan Water District.

It would not be difficult to explain the causes of an increase in the per capita consumption of water in cases where a special kind of manufacturing using large quantities of water has become established in a given city or dictrict, as, for example, the leather industry in the city of Peabody, where the consumption of water per capita has constantly risen, in spite of the general introduction of meters, to over 200 gallons per capita, due to the use of water in its manufacturing industries. But when it is found that, with hardly an exception to the rule, there has been a decided increase in the per capita use of water, after practically complete metering in great cities like Cleveland, Milwaukee, Minneapolis, St. Paul and Providence, and in other cities in all parts of the United States where climatic conditions are similar, including the Metropolitan Water District, it is essential that the causes shall be carefully considered and this tendency taken into account in estimating future water supply requirements.

Increase in Consumption per Capita in English Cities.

Inquiry has also been made of the experience in English cities as to the changes taking place in the consumption of water per capita, and the allowances which are being made therefor, the results of which are shown in the following table: —

City.	Average Increase in Consumption per Capita (United States Gallons per Year).	Years included.
Bradford	.8	1909–18
Glasgow	.4	1909–20
Leicester	.6	1908–20
Manchester	.5	1907–20
Nottingham	.4	1907–20
London	.8	1907–20
Liverpool	.6	1905–19

The results of this inquiry considered in connection with experience in American cities indicate unmistakably that there is likely to be an increase in the consumption of water per capita in the future which must be allowed for in estimating water supply requirements.

Causes of Increase in Water Consumption.

The causes of this general increase in the per capita consumption of water are no doubt due in part to gradually improving standards of living, and to the growth in business and industry. A public water supply system supplies water for many purposes besides strictly domestic consumption. Large quantities are used in manufacturing processes, for mechanical purposes, and in building operations, as well as for fountains, for the flushing of water mains and sewers, for the extinguishment of fires, and for many other purposes.

It has been impracticable to determine the relative quantity of water used for various purposes in the Metropolitan Water District, but the relative amounts drawn for various purposes in an industrial city are indicated by the following record of consumption of water in the city of New Bedford in 1920:[1] —

[1] Kindly furnished by Mr. S. H. Taylor, acting superintendent of water works.

	Consumption per Capita (Gallons).	Per Cent of Total.
Domestic consumption	28	36
Manufacturing and mechanical uses	41	52
Testing, flushing, fountains and all other purposes, including fires.	9	12
Totals	78	100

If the Metropolitan Water District continues to grow, its business and manufacturing will also continue to grow, and the demand for water for business and industrial uses is sure to be an increasing one. This will no doubt mean an increase in the use of water per capita since, in the Metropolitan Water District, water for business and manufacturing uses must come very largely from the public water supply system. In some cases, — for example, in the cities of Fall River, Lowell and Lawrence, — a large supply of water is available for manufacturing purposes of various kinds in the rivers which flow through these cities, and thus these cities avoid the necessity of supplying large quantities of water for such purposes from the public works. In the city of New Bedford, on the other hand, where no such large auxiliary supply of fresh water is available, the consumption of water per capita is much greater than in the cities previously mentioned.

But in addition to probable industrial requirements there is a great demand for more and better housing, and, in general, for higher standards of living. The number of water fixtures in use in dwelling houses has increased steadily for many years and there is no indication that the end has been reached. In residential sections of the Metropolitan District the consumption of water is generally conparatively low, and even in districts comprising chiefly houses of the best class the quantity of water drawn from the public works is probably less than double the quantity used for domestic purposes in the city of New Bedford. On the other hand, in the manufacturing and business sections of the Metropolitan District, and especially in the city of Boston itself, the consumption of water per capita is considerably higher than in the district as a whole. The old city of Boston proper, excluding all annexations, according to the census of 1920, contained a population of 181,193, or less than 25 per cent of the total population of the city in that year, and only a little over 14 per cent of that of the Metropolitan Water District; yet this area contains the principal business center of the entire district, and is peopled during the daytime by many thousands who live in other parts of the district or outside its borders. No doubt a very large quantity of water is used in this comparatively small area by those who live in other places, thus greatly increasing the consumption of water per capita charged to the city of Boston, and possibly reducing somewhat the amount used in suburban districts. This increase will continue as the business district grows.

Auxiliary Supply for Manufacturing.

The question of the possibility of reducing the consumption of water in the Metropolitan Water District by the use of auxiliary sources of supply which might furnish large quantities of water for manufacturing and similar uses, but which would not be suitable for domestic purposes, has been raised from time to time in connection with previous investigations. The only large sources of supply of fresh water available are the rivers which flow through the district, — the Charles, the Mystic and the Neponset, — which carry considerable volumes of fresh water, especially in the winter and spring; but a large part of the flow of the Charles River is withdrawn during the greater part of the year, before it reaches the Metropolitan Water District, by the water supplies already established in its watershed, and the water of the Charles River Basin is consequently largely salt during much of the year. The water of the Neponset River is used for industrial purposes, and during the drier part of the year is generally too badly polluted for use for such purposes within the limits of the Metropolitan Water District. The same has gradually become the case with the fresh-water portion of the Mystic River, which drains a large and growing industrial district in Winchester, Woburn and Stoneham. The only other sources of auxiliary water supply are wells of which there are numbers throughout the district.

Some of these, in localities where the conditions are favorable, furnish a considerable quantity of water, but aside from certain localities in the district in which the possibility of ground water supplies is already largely developed, the areas in which considerable quantities of well water can be obtained are limited, and the agregate amount of water obtained in this way is insignificant as compared with the quantity used from the public works. There is consequently little to expect in the way of increased water supply from the further development of local sources for industrial uses, and it is likely that the draft of water for such uses from the metropolitan system will become greater as time goes on.

Further Prevention of Losses by Leakage.

The question of the possibility of reducing the consumption of water per capita by the employment of further measures for the prevention of waste in addition to the use of meters is one which is receiving much attention by the Boston water department, the investigation being directed especially to the determination of the probability of loss of considerable quantities of water from leaky pipes. The result of these investigations show, as was expected, that a considerable loss of water occurs at times from broken or defective pipes, the water lost finding its way into an adjacent sewer or near-by stream or part of the harbor instead of into cellars where its presence would be noted and the defect quickly remedied. These studies, so far as they have been carried, indicate that the preventable loss of water in this way is probably not great, and it is likely to persist and to be more or less constant even with the most efficient inspection practicable, especially in some of the older parts of the city where the water pipes have been laid for many years in streets in which numerous other pipes and structures have been placed, increasing the danger of breaks and leaks. It is probable that a saving of water can be made in this way, but there is no indication from the studies thus far made that enough water can be saved to effect a material reduction in the consumption of water in the Metropolitan Water District. Nevertheless, the work is of the highest importance in preventing a greater increase in the consumption of water, and, of course, also in preventing danger of loss and damage in other ways.

There is apparently a material loss of water in distributing systems, since it is generally the case that in a municipality where all of the services are metered the total quantity of water measured by the meters rarely exceeds about 75 per cent of the quantity delivered into the mains, while in many cases the proportion accounted for is considerably less. A large proportion of the difference between the aggregate readings of the meters and the amount of water delivered into the mains in water supply systems generally is probably due to failure on the part of the meters to register the full amount used. Some of the loss indicated by this difference is no doubt due to leakage from mains and service pipes, but most of the loss occurring in this way is probably due to numerous comparatively small leaks which are distributed over so great a length of pipe line that the cost of eliminating them would be obviously prohibitive. While in earlier years, when water mains were sometimes constructed of inferior material or without sufficient care, the losses were in some cases large, it is probable that such installations have been largely eliminated, and it is doubtful whether there is material preventable loss by leakage from water mains in the Metropolitan Water District at the present time.

Considering all of the information available, there is no likelihood that any important further saving can be effected in the use of water in the Metropolitan Water District by the prevention, so far as practicable, of leakage from water pipes, such as would reduce materially the consumption of water per capita or make possible the postponement of the construction of works for an additional supply.

Consumption of Water per Capita in Great Cities of the United States.

It is of interest, in considering the probable future consumption of water in the Metropolitan Water District, to determine whether the consumption per capita is excessive as compared with that of other great cities at the present time, and for this purpose the following table is presented showing a comparison of the consumption of water per capita in the Metropolitan Water District with that in the other great northern cities of the United States east of the Rocky Mountains, where climatic conditions are similar to those at Boston, in which the population is in excess of 400,000.

Comparison of Consumption of Water per Capita in the Metropolitan Water District with Consumption in Northern Cities of the United States where Population is in Excess of 400,000.

	Population, Census of 1920.	Per Capita Consumption (Gallons), 1920.	Per Cent Metered Services.
New York	5,620,048	131	–
Chicago	2,701,705	253	–
Philadelphia	1,823,779	170	23
Boston Metropolitan District[1]	1,252,903	104.5	75.6
Detroit	993,678	144	97
Cleveland	796,841	152	100
St. Louis, Mo.	772,897	135	8
Baltimore	733,826	154	3
Pittsburgh	588,343	236	38
Buffalo	506,775	274	8
Milwaukee	457,147	134	99
Washington	437,571	144	85
Newark	414,524	108	92
Cincinnati	401,247	123	99

[1] Including Newton.

It will be seen from this table that the consumption of water per capita in the Boston Metropolitan Water District is less at the present time, and, in all cases except in Newark, decidedly less than in any great city in the United States where climatic conditions are similar and in which the population exceeds 400,000. Conditions of living and of industry are probably much the same, in all of the eastern cities at least, and the facts presented in the table furnish no basis for expecting that the use of water in the Metropolitan Water District can be reduced materially below the amount used at the present time.

Year to Year Variations in Water Consumption.

While in estimating the consumption of water per capita in the future it has been necessary to assume that the increase will be practically a constant amount, somewhat more rapid, perhaps, in the earlier years and lessening as time goes on, there will continue, undoubtedly, to be wide variations in the consumption of water per capita from time to time as has been the case in the past. These variations are due to a variety of causes, among the more important of which are the activity of business and industry, meteorological conditions, the efficiency of methods of preventing unnecessary use and waste, and changes in other respects.

Business and industrial conditions have a material effect on the consumption of water because of its extensive use for mechanical, manufacturing and general industrial purposes. The great business depression of 1921, coupled with an exceedingly warm winter and a wet summer, will no doubt cause a marked decrease in the consumption of water per capita in that year, but with the inevitable revival in business and industry, and especially when activity in building construction is again established, a marked increase will no doubt again take place in the use of water per capita, as has been the case in similar circumstances in former years.

Meteorological conditions — heat, drought, excessive cold or unusual rainfall — produce marked variations in the consumption of water from year to year. In very dry periods much more water is used than in years of average rainfall, and in periods of great heat, also, the draft upon the water supply is much larger than usual. Excessive rainfall, on the other hand, reduces the draft of water from the public works. More marked, even, than great heat or drought is the effect of cold winters in increasing the use of water, and of unusually mild winters in decreasing it. An illustration of the difference in the use of water in a very cold winter as compared with a mild one is afforded by a comparison of the record of water consumption in the winter months of the year 1917–18 with that of the year 1918–19. This comparison is shown in the following table: —

Month.	1917-18. Mean Temperature, Boston (Degrees Fahrenheit).	1917-18. Average Daily Water Consumption, Metropolitan Water District (Million Gallons).[1]	1918-19. Mean Temperature, Boston (Degrees Fahrenheit).	1918-19. Average Daily Water Consumption, Metropolitan Water District (Million Gallons).[1]
December	23.7	118.320	34.7	121.619
January	21.0	144.527	33.2	126.860
February	26.9	159.833	32.6	121.019
March	36.7	137.042	40.8	114.622

[1] Excluding Newton.

Another cause of variation in the consumption of water from the public works in the past has been that caused by the varying efficiency of methods adopted for the prevention of waste. In earlier years inspection was relied upon to prevent loss of water in this way, but not until the application of meters to water services generally furnished an effective means of preventing unnecessary waste by charging for it at the usual rates was an adequate method of waste prevention put in force. That this method has been most effective in preventing excessive use and waste of water is well shown by the decrease in the consumption of water in nearly all cities, including the Metropolitan Water District, following the beginning of the general introduction of meters, — a decrease that was doubtless due in part to the fear of larger water bills under the meter system; but since experience did not show that the use of meters caused a materially higher charge to the householder than the former system, provided the plumbing were kept in reasonably satisfactory condition, and since in a great many cases the charge was less than before the meter was applied, less care is exercised in the amount of water used than was formerly the case.

The conclusion to be drawn from the experience of the cities in which service pipes are largely or wholly metered is unmistakable so far as it goes, and the experience in a number of cases covers a considerable period of years. This experience shows clearly that notwithstanding the general use of meters an increase in the use of water per capita is taking place at the present time in all cities practically without exception. The continued use of meters can probably be depended upon to prevent such great increases as were experienced before their use began and to keep the increase within reasonable limits. This increase will vary from causes such as those already indicated, but that it can be prevented in the future by any means which are now available seems improbable.

The important fact is that the cost of water to the average householder is so small as to be almost trivial to many if not most water consumers. The unpolluted supplies of palatable water, soft and free from excessive color or objectionable taste and odor, distributed so cheaply in nearly all cities and villages, have had more to do in improving the health and comfort of the inhabitants of modern communities than any other service maintained by the public. When this service is supplied at a cost which is insignificant as compared with its value, it is not to be expected that there will be a material reduction in the consumption of water per capita in the future, unless a material change takes place in social and industrial conditions, or unless the cost of water becomes materially greater than is the case to-day.

Summary of Reasons for Probable Increase in the Consumption of Water per Capita.

Before stating the actual estimates of consumption of water per capita, and the probable requirements which should be allowed for in the ensuing years, a brief review of the essential facts which have been stated in detail in the foregoing pages may help to bring out the governing principles which lead to an opinion as to probable future requirements.

In the first place, and this is most important, it is evident that in the past the succeeding years have brought with them a variety of conditions, many of them unforeseen, which have influenced greatly the quantity of water used. Furthermore, in spite of the introduction of meters, and in the face of the laudable desire, and even the prophecies, of those operating the works, the fact is that there has been, on the whole, a steady increase in the per capita consumption of water ever since a water supply was first introduced in the principal city of the district many years ago.

The reasons for this increase are —

1. The introduction of ample supplies of pure water, soft and of excellent appearance, and capable of advantageous use for a large number of purposes.

2. A gradually improving standard of living, accelerated no doubt by the experiences of the war which have led to a demand for better housing, more plumbing fixtures, and other aids to comfort and health obtainable through a freer use of water from the public works. New uses are constantly found; for instance, the extension of the use of the swimming tank alone may mean a material increase in the use of water as it will in the comfort and pleasure of those to whom such facilities are available.

3. The increasing use of water for manufacturing and mechanical purposes, especially in the Metropolitan District, where there are no large quantities of fresh water suitable for such uses.

4. A large use of water by the daytime population in the city of Boston which consists to a material extent of those living outside the Metropolitan Water District.

5. Unpreventable waste from numerous small leaks which could be repaired only at excessive cost, and which, with aging pipes and structures, will doubtless continue notwithstanding the fact that a large amount of waste has been and must continue to be eliminated to the full practicable extent.

6. It is evident that metering is the only equitable way of selling water, and that the continued use of meters is absolutely necessary in order to prevent an inordinate increase in the consumption of water per capita. Wholly metering the services after 75 per cent have been metered, however, has had no material effect in reducing the consumption of water, while, on the contrary, the common and well-nigh universal experience has been that the per capita consumption continues to increase, notwithstanding the increase in the number of meters.

7. The consumption of water per capita in the Metropolitan District is not excessive when compared with cities of similar size in this country. On the contrary, it is now less, even decidedly less, than in any city of similar population and climatic conditions in the United States, and the per capita consumption in equally metered cities is steadily growing.

8. Even in English cities, where the standards are different and the people accustomed to a lower per capita consumption, the per capita use of water is increasing from year to year.

9. New industries must be served with water and new housing provided for, and while depressions will occur when less water will be used, every succeeding peak of industrial activity has shown a higher consumption of water per capita than in the past.

10. Heat, drought and excessive cold all produce marked variations in the consumption of water, and it has been found necessary, according to the records of the operation of water works, to make large and unexpected allowances for variations from such causes. Extremes of temperature and rainfall such as have occurred in the past will occur again, and are likely to occur in even greater severity.

11. The cost of water is and will continue to be exceedingly small for a long time to come. In fact, the present price for the average family seldom exceeds the cost of a morning and evening newspaper. The householder naturally is taking advantage of the low price of this commodity to enhance his enjoyment of life and to improve his health and comfort by using it more and more freely from year to year. When the amount of water he uses is measured, and he pays for just what he uses, the householder soon learns that its cost is insignificant when compared with its value. At the same time, he is paying the entire cost and practically none of it comes out of general taxation; in fact, in several municipalities in the Metropolitan Water District a large contribution is made from the water revenue to general municipal expenses, to the benefit of the general tax levy.

12. An abundance of water during periods of excessive cold, as in the winter of 1917–18, means the saving of valuable plumbing fixtures, piping systems and the furnishings of dwellings, but, more than all, may mean the protection of health and life, for there is no public service the failure of which is capable of equally serious consequences. In periods of great heat, also, an ample water supply assures the protection of vegetation, and, above all, adds greatly to the comfort of all, especially of the inhabitants of densely populated areas.

In the face of the evidence that the use of water has been ever a constantly increasing one, and that indications point to a growing use in the future, it would be unreasonable to ignore the facts as to this increasing use, and while every legitimate effort must be made to keep the water consumption within reasonable limits, it does not follow that the health of the people should be placed in jeopardy, or even that the public should be put to serious inconvenience, because of an assumption that means can and will be found and applied in the immediate future to restrict the growing use of this important commodity.

Estimated Increase in Water Supply Requirements of Metropolitan Water District.

In the cities included in the table on page 65 the increase in the consumption of water per capita has ranged, as a general rule, from 0.75 to 2.50 gallons per person per year, and has averaged in these cities about 1.42 gallons per year, or 1.31 if the year 1920 be omitted. If comparison is made of the consumption of water in the cities of Boston, Somerville, Chelsea and Everett in the early 80's, when effective measures were being enforced to prevent unnecessary use and waste of water, with the consumption of water in the same municipalities in 1920; it appears that, notwithstanding the general introduction of meters and the efforts to prevent waste by other methods in the later years of that period, there has been an increase in the consumption of water per capita of about 1.3 gallons per person per year. It is probable that, if meters had been in use generally in the early 80's, the consumption of water would have been less at that time and the increase in the last forty years somewhat greater than 1.3 gallons per year. It seems reasonable to assume that the future increase will not exceed 1.3 gallons per year.

In estimating the future consumption of water per capita in the Metropolitan Water District it is assumed that the amount of water used will be reduced in the next few years following the year 1920 by the application of meters to unmetered services, and that in consequence of this reduction the consumption per capita will not again rise above 105.5 gallons until after 1925. Beyond that year it is estimated that the rate of increase will average about 1 gallon per capita per year, being slightly greater in the earlier years, but growing less as time goes on. Other than the complete metering of all services, including the effective maintenance of the meter system and the prevention of losses of water by leakage, so far as it is practicable to prevent them, there appear to be no further means available for reducing materially the consumption of water per capita at the present time unless by some form of rationing water which under present conditions would doubtless be deemed impracticable and objectionable.

On the basis of the estimate of the probable consumption of water per capita in the future herein presented, and using the estimates of population already given, the following table and diagram have been prepared showing the quantity of water which may be required for the supply of the Metropolitan Water District within the next fifty years: —

Table showing Population, Water Consumption in Thousand Gallons per Day and Daily Consumption per Capita in Gallons, in the Metropolitan Water District and in the City of Newton from 1920 to 1970.

	1920.[1]			1925.			1930.			1935.			1940.			1945.		
	Population.	Per Capita Consumption.	Total Consumption.	Population.	Per Capita Consumption.	Total Consumption.	Population.	Per Capita Consumption.	Total Consumption.	Population.	Per Capita Consumption.	Total Consumption.	Population.	Per Capita Consumption.	Total Consumption.	Population.	Per Capita Consumption.	Total Consumption.
Metropolitan District.	1,206,849	105.5	127,265	1,333,680	105.5	140,703	1,463,870	111.8	163,661	1,592,460	117.8	187,592	1,721,550	123.4	212,439	1,851,730	128.5	237,947
Newton . .	46,054	80.1	3,687	50,200	85.0	4,267	54,500	89.6	4,883	58,900	94.0	5,537	63,200	98.2	6,206	67,600	102.2	6,909
Total .	1,252,903	104.5	130,952	1,383,880	104.7	144,970	1,518,370	111.0	168,544	1,651,360	116.9	193,129	1,784,750	122.5	218,645	1,919,330	127.6	244,856

	1950.			1955.			1960.			1965.			1970.		
	Population.	Per Capita Consumption.	Total Consumption.	Population.	Per Capita Consumption.	Total Consumption.	Population.	Per Capita Consumption.	Total Consumption.	Population.	Per Capita Consumption.	Total Consumption.	Population.	Per Capita Consumption.	Total Consumption.
Metropolitan District .	1,979,870	132.9	263,125	2,111,080	136.8	288,796	2,241,270	140.5	314,898	2,373,500	144.0	341,784	2,501,170	147.3	368,422
Newton	71,800	106.0	7,611	76,000	109.5	8,322	80,300	112.5	9,034	84,500	115.5	9,760	88,800	118.5	10,523
Total	2,051,670	131.9	270,736	2,187,080	135.8	297,118	2,321,570	139.5	323,932	2,458,000	143.0	351,544	2,589,970	146.3	378,945

[1] 1920 figures actual; others estimated.

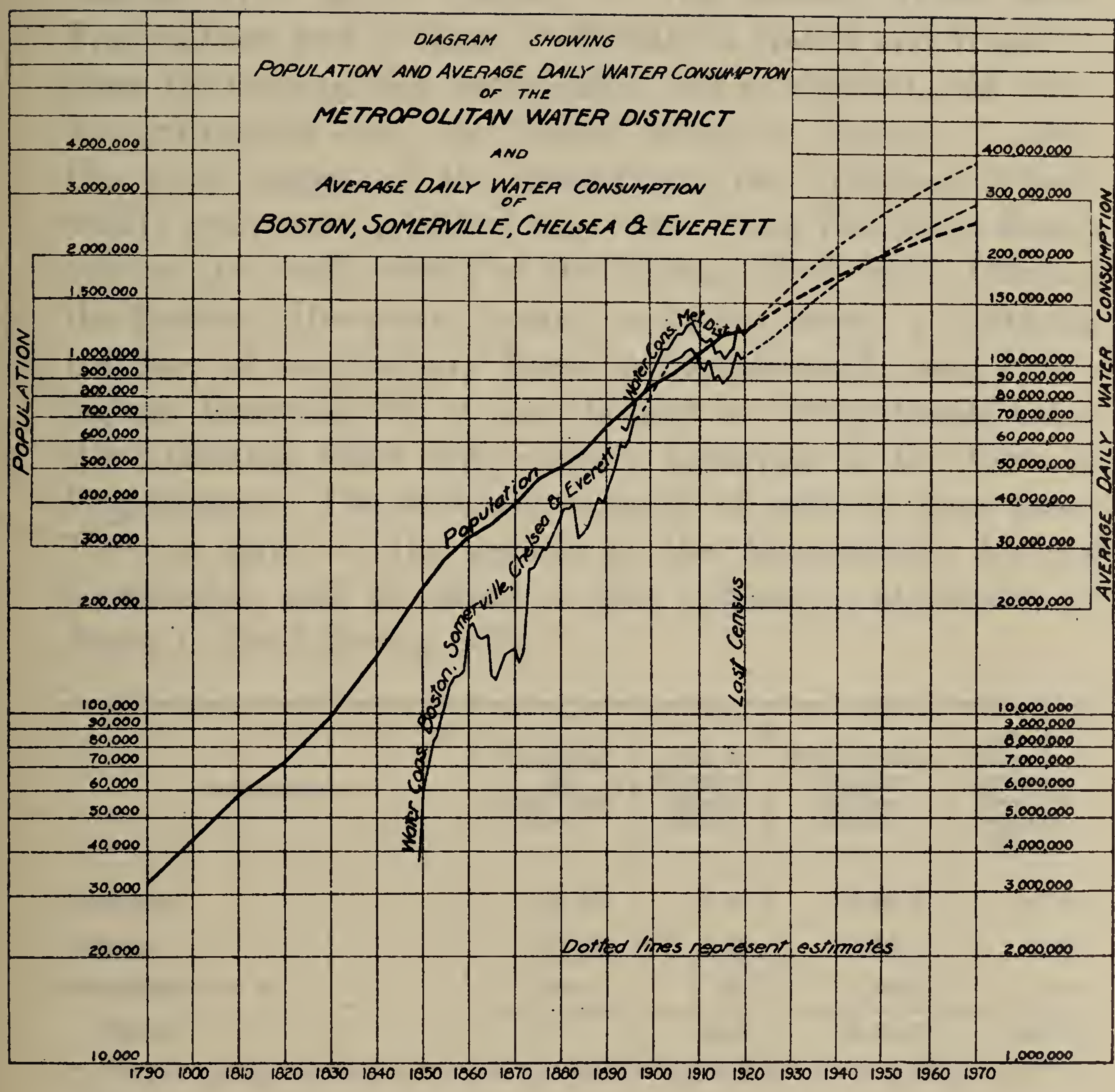


DIAGRAM SHOWING
POPULATION AND AVERAGE DAILY WATER CONSUMPTION
OF THE
METROPOLITAN WATER DISTRICT
AND
AVERAGE DAILY WATER CONSUMPTION
OF
BOSTON, SOMERVILLE, CHELSEA & EVERETT
POPULATION
AVERAGE DAILY WATER CONSUMPTION
4,000,000
3,000,000
2,000,000
1,500,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
400,000,000
300,000,000
200,000,000
150,000,000
100,000,000
90,000,000
80,000,000
70,000,000
60,000,000
50,000,000
40,000,000
30,000,000
20,000,000
10,000,000
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
Population
Water Cons. Boston, Somerville, Chelsea & Everett
Water Cons. Met. Dist.
Last Census
Dotted lines represent estimates
1790 1800 1810 1820 1830 1840 1850 1860 1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970

PART II. ADEQUACY OF PRESENT SOURCES OF SUPPLY OF METROPOLITAN WATER DISTRICT.

Present Sources of Water Supply of the Metropolitan Water District.

The sources of water supply available for the use of the Metropolitan Water District at the present time are (1) the Nashua River above Clinton, (2) the Sudbury River above Framingham, and (3) Lake Cochituate in Natick and Wayland. Since the metropolitan water works were established, and water was introduced from the Nashua River on January 1, 1898, the water supply of the district has been obtained almost wholly from three principal reservoirs, — the Wachusett Reservoir on the south branch of the Nashua River above Clinton; the Sudbury Reservoir, located on Stony Brook, a northerly tributary of the Sudbury River in Southborough; and Framingham Reservoir No. 3, also located on Stony Brook but a short distance below the Sudbury Reservoir in the town of Framingham. The area and capacity of each of these reservoirs as given in the reports of the Metropolitan District Commission, and the areas of their tributary watersheds, are shown in the following table: —

Reservoir.	Elevation[1] of High Water (Feet).	Area of Reservoir (Square Miles).	Total Storage Capacity (Million Gallons).	Area of Watershed, including Reservoir (Square Miles).
Wachusett	395.00[2]	6.46	64,968.0	108.84[3]
Sudbury	260.00	2.21	7,253.5	22.28
Framingham No. 3	186.74	.39	1,199.7	5.40
Totals	–	9.06	73,421.2	136.52

[1] Elevation above Boston city base.

[2] It is possible, by use of flashboards, to raise the water to elevation 397. At that elevation the capacity of the reservoir would be 67,686.1 million gallons.

[3] Exclusive of areas diverted by the city of Worcester amounting to 9.35 square miles.

While these sources have furnished practically the entire water supply of the district since the completion of the metropolitan water works, their safe yield is but little in excess of the quantity of water consumed by the district in 1920 without making allowances for other drafts of water from the Wachusett system. It is obvious that at the rate of increase in the use of water which has prevailed in the district for a number of years the quantity required for water supply purposes under normal conditions will exceed the safe capacity of these sources of supply within the next few years. It will, therefore, soon be necessary again to draw water continuously from some of the remaining sources under the control of the district. These sources are the reservoirs on the southerly branch of the Sudbury River in Framingham, Ashland and Hopkinton, together with Lake Cochituate, the original source of water supply of the city of Boston. The area and capacity of each of the storage reservoirs in these watersheds, including Lake Cochituate, are given in the following table, together with the area of watershed tributary to each: —

Reservoir.	Elevation[1] (Feet).	Area of Reservoir (Square Miles).	Total Storage Capacity (Million Gallons).	Area of Watershed, including Reservoir (Square Miles).
Ashland	225.21	.27	1,416.4	6.43
Whitehall	337.91	.94	1,256.9	4.35
Hopkinton	305.00	.30	1,520.9	5.86
Framingham No. 2	177.87	.21	529.9	28.50
Framingham No. 1	169.32	.23	289.9	1.84
Cochituate	144.36	1.14	2,097.1	17.58
Farm Pond	159.25	.26	167.5	.54
Totals	–	3.35	7,278.6	65.10
Wachusett system	–	9.06	73,401.5	136.52
Total of all sources under the control of the Metropolitan Water District.	–	12.41	80,680.1	201.62

[1] Elevation above Boston city base.

Estimate of Safe Yield of Present Sources.

In computing the safe yield of all of the available sources of water supply of the Metropolitan Water District it is necessary to take into account the fact that none of these supplies is filtered, and that in the case of the reservoirs of the Wachusett system a thorough preparation of the reservoirs for storage purposes, and especially a long period of storage, are relied upon for the purification of the water before it is delivered to the district. It is therefore essential to retain enough water in these reservoirs at all times to secure adequate purification by storage.

On the portion of the Sudbury River watershed not included in the Wachusett system two of the reservoirs were thoroughly prepared for the storage of water at the time they were constructed, but the main reservoirs on this river are located on tributary streams in the upper parts of the watershed, and as there are large areas of swamp along the main stream below them but above the small lower reservoir known as Framingham Reservoir No. 2, the water of the latter reservoir is usually highly colored.

Lake Cochituate furnishes water of very poor quality which, though not very highly colored, contains much organic matter and is usually affected by an objectionable taste and odor. Both the southern Sudbury and Cochituate watersheds, especially the latter, contain large populations per square mile, and neither of these sources should be used regularly for the water supply of the district unless properly filtered. It is accordingly assumed in estimating the safe capacity of the metropolitan sources that enough water will be retained in the reservoirs of the Wachusett system to secure sufficient purification by storage to render the water safe and acceptable for use, and that the water of the southern Sudbury and Cochituate sources will be purified by filtration as soon as it becomes necessary to use them again for the supply of the district. For these reasons, in estimating the combined yield of the various watersheds, allowance has been made for retaining in the Wachusett Reservoir 14,800,000,000 gallons; in the Sudbury, 7,000,000,000 gallons; and in Framingham Reservoir No. 3, 800,000,000 gallons. In all the other reservoirs and in Lake Cochituate combined allowance has been made for retaining only 1,417,000,000 gallons, a large amount of which would remain in Lake Cochituate and should be retained there to prevent objectionable odors from the exposed bottom of the lake. These allowances are much lower than desirable, especially in the case of the Wachusett Reservoir, since if the water were reduced to so low a level a water of poorer quality would be delivered to the district, containing a considerably greater quantity of organic matter than is present in the water now used, and having a noticeable color.

Deductions and Losses in Estimate of Safe Yield.

The estimated gross yield of all of the present sources of supply of the Metropolitan District, as given in the report of the State Board of Health upon a metropolitan water supply in 1895, was 173,000,000 gallons per day. Since that time, however, water from a part of the Wachusett watershed has been diverted for the use of the city of Worcester and the area of the Wachusett watershed reduced from 118.19 to 108.84 square miles. Not all of the flow from this part of the Wachusett watershed has thus far been diverted by the city of Worcester, but when the Pine Hill Reservoir now under construction by that city is completed it will be practicable to divert the entire flow of this area, and in computing the safe yield of the metropolitan watersheds it is necessary to assume that the total flow of this area will be diverted from the Wachusett watershed in dry periods. It was estimated in the report of 1895 that the diversion of the water from the area recommended for the city of Worcester would reduce the gross yield of the sources about 8,500,000 gallons per day. With these allowances for storage and for the diversion of water by the city of Worcester, the gross yield of all of the sources of water supply of the Metropolitan District during the most recent dry period, which began in the year 1908, was about 169,000,000 gallons per day.

Not all of this water, however, is available for the use of the Metropolitan Water District. A part of it must by law be discharged below the lowest dams on the Nashua and Sudbury rivers, a part of it is lost by leakage, a part is used for the water supply of the cities and towns located within or adjacent to the metropolitan watersheds and which are authorized to take water therefrom, a further part of it is lost by leakage into sewerage systems in those watersheds, through which it is diverted to points outside their limits, and there are also unavoidable losses in other ways chiefly from inability to foresee conditions sufficiently well to store and draw the water always to the best advantage.

Under the Sudbury River Act, so called (chapter 177 of the Acts of the year 1872), the city of Boston and its successor, the Metropolitan Water District, are required to allow 1,500,000 gallons of water per day to flow down the river below the lowest dam at Framingham, thus reducing by that amount the quantity of water available from the Sudbury sources.

The Metropolitan Water Act (chapter 488 of the Acts of 1895) provides as follows: —

> SECTION 4. Said board may take, by purchase or otherwise, the waters of the south branch of the Nashua river, at and above a point above the dam of the Lancaster Mills in the town of Clinton, but shall allow not less than twelve million gallons of water to flow from a reservoir above said dam in each week, and such further quantity, not exceeding twelve million gallons a week, as the owner of said mills shall from time to time certify to be necessary for use therein and in other buildings now or hereafter owned by him, for domestic and manufacturing purposes, other than the production of water power, and said board, in regulating the flow of said quantities, shall, as far as practicable conform to any reasonable request in writing of the owner of said mills; . . .

Under the provisions of the Metropolitan Water Act it is necessary to allow a maximum of 3,428,000 gallons per day to flow from the Wachusett Reservoir in case that amount should be required. The average amount called for has exceeded 3,000,000 gallons per day on the average for several years together, and obviously allowance must be made for the full amount. Hence there is to be deducted from the yield of the water sources of the Metropolitan Water District an aggregate of 4,928,000 gallons per day for water which must be allowed to run past the dams on the Nashua and Sudbury rivers, excepting at times when unavoidable waste furnishes all or part of the necessary quantity, which would rarely occur in a dry period when the maximum yield of the watersheds was being used for the supply of the district.

The further reductions resulting from reservations for the water supplies of cities and towns within or adjacent to the watersheds from which the metropolitan supply is drawn are quite important in considering the net safe yield of the sources of supply.

In the Cochituate Water Act (chapter 167 of the Acts of 1846) the following reservation in section 14 is made for water supplies for towns in the neighborhood of the lake: —

> . . . provided, however, that this act shall not be so construed as to prevent the inhabitants of Natick, Framingham, Sherburne and Wayland from using so much of the water hereby granted as shall be necessary for extinguishing fires and for all ordinary household purposes. . . .

Under this clause water is taken by the town of Natick from a well adjacent to Lake Cochituate, while the town of Wayland takes water from a reservoir on a stream tributary to the lake. Negotiations are under way by which the town of Wayland is likely to take its entire supply of water in future from the Weston Aqueduct of the Wachusett system.

The Sudbury River Act (chapter 177 of the Acts of the year 1872) provides that nothing contained in this act shall be so construed as to —

> prevent the inhabitants of the towns of Framingham, Ashland, Southborough, Hudson and Westborough from taking from the Sudbury or Assabet rivers or Farm Pond so much of the water hereby granted as shall be necessary for extinguishing fires, and for all ordinary domestic and household purposes, and for the generation of steam, or from cutting and carrying away ice from said pond; or as to prevent the Boston and Albany Railroad Company, or the Mansfield and Framingham Railroad Company, or the Boston, Clinton and Fitchburg Railroad Company from taking water from Farm Pond, for use in locomotive or other engines, or for other railroad purposes, under such regulations of the city council of the city of Boston as may be essential for the preservation of the purity of the same.

The town of Framingham has for many years obtained its water supply in part from filter galleries near Farm Pond in the Cochituate watershed, into which water is diverted from metropolitan sources when necessary, and in part from the Sudbury Aqueduct. Negotiations are now pending for supplying Framingham wholly from the Wachusett system. The Boston & Albany and the New York, New Haven & Hartford railroads use water from the pond in some years to an amount considerably in excess of the safe yield of that source.

The towns of Ashland, Hopkinton and Westborough take water from sources within the Sudbury River watershed.

In the Metropolitan Water Act (chapter 488 of the Acts of 1895) provision is made for the water supplies of several towns, as follows: —

SECTION 22. The towns of Clinton, Sterling, Boylston, West Boylston, Lancaster, Holden, Rutland, Princeton, Paxton and Leicester, and the city of Worcester, may take from the south branch of the Nashua river, above the dam of the proposed reservoir on said river, so much of the water thereof as they have already been or may hereafter be authorized by the legislature to take, for supplying their inhabitants with water, and in case either of the towns of Lancaster, Holden, Rutland, Princeton, Paxton or Leicester, or the city of Worcester, shall so take water, it shall pay to the Commonwealth, to be paid into the sinking fund for said bonds, a fair proportion of the cost incurred by the Commonwealth for said water and for the construction, maintenance and operation of said works, the same to be determined by the engineer of said board and an engineer to be appointed by the city or town, and if they cannot agree, the proportion shall be determined by a master to be appointed by the supreme judicial court on the petition of either party interested, and the report of such master made and accepted by said court shall be final and binding on all parties.

Of the municipalities mentioned in this act the city of Worcester, as stated before, has already exercised the right under chapter 351 of the Acts of 1902 to take water for water supply purposes from an area within the Nashua watershed above the dam at Clinton, which embraces 9.35 square miles, and in the calculations relating to the yield of the Wachusett system allowance has already been made for the diversion of water from this area for the use of the city of Worcester. Two other towns, Holden and Rutland, have provided themselves with public water supplies by taking water from Muschopauge Lake, within the Wachusett Reservoir watershed, since the metropolitan water works were constructed. A considerable portion of the water used in one of these towns is diverted outside of the watershed of the Wachusett Reservoir. In addition to the water diverted for the supply of these municipalities a small amount is diverted for other purposes.

Besides the deductions for water which must be allowed to run past the dams, and for water withdrawn for the supply of municipalities within the limits of or adjacent to the metropolitan watersheds, there are other allowances which must be made in estimating the net yield available for the Metropolitan Water District. It has been assumed, in making these calculations, that the storage in the reservoirs at the beginning of the dry period was increased from 80,680,100,000 gallons, as given in the reports of the Metropolitan District Commission, to 85,210,000,000 gallons by the use of flashboards on the reservoirs to the fullest possible extent; and furthermore, in drawing the water from the various reservoirs, it has been assumed that these reservoirs will be operated in such a way as to secure the largest possible yield. It has also been assumed that the filters which may be installed in the neighborhood of Framingham Reservoir No. 1 or Framingham Reservoir No. 2 for filtering the water of the southern Sudbury watershed will have a capacity of at least 40,000,000 gallons per day, and those at Lake Cochituate a capacity of 15,000,000 gallons per day. These capacities are greater than the safe yields of these sources, but by building filters of the larger capacity it will be practicable to utilize much of the water which would otherwise run to waste from these watersheds, thus making possible the storage of larger amounts of water in the Wachusett Reservoir at times of high flow in the spring and increasing the safe yield of the sources of supply. In the practical operation of the works, when it would be impossible to foretell the conditions of draft necessary to obtain the maximum yield, considerable water would no doubt be lost in various ways for which allowance must be made in determining the safe net yield of the sources.[1] It is obvious that, as the use of water in the towns on the watershed increases, the diversion of water from the metropolitan watersheds will become greater, and as the sewerage systems are extended the loss of water due to leakage will increase. It is also probable that, while the leakage from the metropolitan aqueducts, reservoirs, and pipe lines in the past has been small, as these structures increase in age the leakage is likely to grow larger. For these reasons the net available yield of the present metropolitan water sources in the future will be a gradually decreasing one. The allowances made for various losses are shown in the following table: —

[1] An allowance of 2 per cent is made, but this loss may be greater.

	Gallons per Day.	
Allowance for water discharged below the Wachusett dam	3,428,000	
For leakage through the north dike	917,000[1]	
For water used by Framingham water works	1,078,000[1]	
For water diverted by sewers	1,272,000[1]	
For water wasted below Sudbury dam	1,500,000	
		8,195,000
For losses in manipulation of filters, storage and draft, 2 per cent	3,380,000	
For growth of towns now taking water from metropolitan watersheds within the next ten years	500,000	
For losses due to new sewerage systems and extensions of old systems	1,000,000	
For maintenance of filters on Sudbury and Cochituate watersheds	450,000	
For leakage through aqueducts, reservoirs and pipe lines	1,000,000	
		6,330,000
Total,		14,525,000

NOTE. — In the above table it is assumed that not more than two of the small towns which now take water from within the metropolitan watersheds will divert their sewage outside that area.

Conclusions as to Safe Yield of the Present Sources.

Deducting the above amount from the gross safe yield of the sources, viz., 169,000,000 gallons per day, the net available safe yield of the present sources of supply will amount in 1930, in round numbers, to about 154,000,000 gallons per day. No allowance has been made in this estimate for water sold outside the district, though a small amount has been sold in each year for several years, and in dry periods much larger quantities. Furthermore, no allowance has been made for the taking of water from the metropolitan watersheds by any of the other municipalities having rights reserved in those waters. It will be noted that the safe yield of the metropolitan sources has been calculated on the basis of the rainfall and yield of these watersheds in the most recent dry period. The rainfall records

[1] Average of three years ending with 1920.

of New England indicate that such periods occur five or six times in a century, and that in some of the dry periods of the past there has been a smaller precipitation, and hence, no doubt, a considerably smaller yield of watersheds, than in the dry period which began in 1908. In this estimate, also, no allowance has been made for the yield of Farm Pond because the railroads may use more water from this pond than its watershed can be relied upon to yield. It is probable that the town of Framingham will in the near future take its water supply from the Wachusett system and discontinue the use of the filter galleries near Farm Pond, the water of which is affected unfavorably by drainage from the densely populated areas in their neighborhood. Even after this change is made, however, it is probable that metropolitan water will have to be obtained in dry seasons to maintain the level of Farm Pond, though no allowance for such probable diversion is made in these estimates.

Before considering the relation of the safe yield of the metropolitan sources to the consumption of water in the present Metropolitan District, it is essential to consider the possible requirements of the city of Newton, already a part of the district, which has hitherto supplied itself from independent sources.

Water Supply of the City of Newton.

The city of Newton, though a part of the Metropolitan Water District, has continued to supply itself with water, except in emergencies, from its own sources near the Charles River up to the present time. The capacity of these sources has recently been the subject of a careful study by the city engineer of Newton, who has recommended to the city government that application now be made for taking metropolitan water to meet the requirements of the city above the yield of present sources, provided an agreement can be made with the Metropolitan Water District whereby the city of Newton will guarantee to furnish from its own works 4,000,000 gallons of water per day and will be credited for the same under the provisions of chapter 422 of the Acts of the year 1913, entitled "An Act relative to allowances to cities and towns in the Metropolitan Water District for water furnished from their own sources."

The water supply of the city of Newton is drawn from ground sources along the westerly side of the Charles River in the town of Needham. The works are all included within a water works reservation of some 750 acres, of which 655 are on the Needham side, extending from Needham Street to a point about 10,500 feet south of Kendrick Street or to the Needham–Dedham town line. Within this area are located a series of conduits, lying approximately 10 feet below the ordinary level of the water in Charles River, to which are connected a collecting system of open-joint pipes and a large number of tubular wells. At the extreme southerly end of this system is a large well which has been excavated to a level about 32 feet below that of the conduit near by. The water level when pumping from this well ranges from 21 to 27 feet below this conduit. Further extension of the collecting works along the river in a northerly direction is impracticable on account of unfavorable conditions there, both as to the character of the soil and the presence of population in this region. On the south further extension is limited by the water reservation of the town of Brookline.

The quality of the water of the Newton water supply has remained good with little change for a long period of years, in marked contrast to the great deterioration that has taken place in some of the other ground-water supplies in the Charles River valley. The maintenance of satisfactory conditions in this case is no doubt due to the fact that this supply has not been greatly overdrawn. The fact that the water from the latest structure, a large deep well near the southerly end of the Newton water supply reservation from which water is drawn to a greater depth than from the other sources, shows a tendency to deteriorate, though in use a much shorter time than the other sources, is an indication of what might happen if the ground water were lowered to the extent that has been the case with the collecting systems in some other municipalities. It is not improbable that a reduction in the draft from the large well may have to be made in the future to maintain the water in suitable condition, and such a reduction would tend to reduce the quantity of water that can be supplied from these works. How long this supply can be maintained in its present purity is still uncertain, the result depending in part upon the avoidance of an excessive draft, but also in part upon the growth of population in the neighborhood, and, of equal or perhaps greater importance, upon the maintenance of clean water in the river itself.

The water of the Charles River opposite the Newton pumping station has shown a gradual deterioration for many years. In the lower part of the Charles River watershed, including the town of Dedham, all of the municipalities are provided with systems of sewerage by which domestic sewage is kept from entering the river, and a recent extension of the metropolitan sewerage system up the river from Dedham provides an outlet by which the sewage of Wellesley and Needham can be diverted from the watershed. Sewers have already been constructed in Wellesley and connected with the metropolitan sewerage system, and the construction of similar works in Needham will probably not be long delayed. In the upper reaches of the river the larger towns have provided themselves with systems of sewerage and sewage disposal in recent years by which domestic sewage is largely diverted from the river, though lack of care in the operation of at least one of these works has resulted in the pollution of the river by more or less crude sewage in recent years; but while provision has been made for removing the sewage from this river, its pollution by manufacturing waste has been increasing, and the quality of the river water is gradually deteriorating. A large part of the water supply of the city of Newton is undoubtedly derived from the Charles River by filtration through the ground, and in consequence the character of this water is likely to be affected materially by the condition of Charles River. If the pollution continues to increase in the future it will undoubtedly have an unfavorable effect upon the character of this water supply.

The population in the neighborhood of the wells on lands draining toward the gravel deposits from which the water is drawn is very small at the present time, and thus far has had little effect upon the quality of the water. While the mineral content of the water is gradually increasing, this condition is undoubtedly due largely to the deterioration of the river water, though a small portion of it may be derived from the sparse population in the region in which the wells are located. Considering the large area of land controlled by the city in this region, and the lack of transportation facilities in adjacent territory, it is likely that deterioration from the growth of population in this neighborhood will be slow for many years, notwithstanding the nearness of this area to the city of Boston (between 8 and 9 miles from the State House).

At various times up to 1913 the city of Newton was granted the right to take water from the Charles River or its watershed to an aggregate amount not exceeding 5,000,000 gallons per day, and in 1913 the city was further authorized to take an additional quantity amounting to 3,000,000 gallons per day, or such part thereof as might be approved by the State Department of Health, making a total of 8,000,000 gallons per day which might under certain circumstances be drawn from the Charles River watershed. Restrictions imposed by the State Department of Health under this act, however, require that the amount of water drawn from the river shall be proportionate to the rainfall, and in years of low rainfall the draft is restricted to 5,000,000 gallons per day. These restrictions, imposed for the purpose of maintaining proper sanitary conditions in the river below the Newton water works, are unlikely to be changed in the direction of allowing a greater draft of water from this watershed in the future, unless adequate compensation is made for maintaining the flow of the stream by the construction of a storage reservoir of sufficient capacity in the watershed of the river farther upstream. Considering the difficulties in the way of such a project, it is unlikely to be found practicable.

There are, of course, large fluctuations in the seasonal and daily use of water in the city of Newton as in other municipalities, and while these are equalized to some extent by the storage available in the distributing reservoirs, the use of water in periods of maximum consumption is, nevertheless, considerably in excess of the average for the year. With the maximum limit of 5,000,000 gallons per day in dry years the average daily consumption, taking the year as a whole, cannot much exceed three-fourths of that limit, or 3,750,000 gallons per day, without danger of exceeding the maximum in periods of high consumption. Under these conditions the sources of water supply of the city of Newton used alone cannot be relied upon to yield in dry periods much more than 3,750,000 gallons per day, a quantity which is less than 100,000 gallons per day in excess of the amount used by the city in 1920.

It is not improbable, furthermore, that the supply obtainable in the future may be even less than this quantity in a very dry period, since the increase in the amount of water drawn from the river or its tributaries for water supply purposes at points above, and the diversion of water by extensions of sewerage systems in those regions, will undoubtedly lower the flow of the river in the neighborhood of the Newton water works in the future. If used in connection with the metropolitan sources of water supply, however, it will no doubt be practicable, for some years at least, to draw a greater average quantity from the Newton sources than they can supply independently in a very dry period, and the estimate of a safe yield of 4,000,000 gallons per day from these sources if used in connection with the sources of the Metropolitan Water District appears to be a reasonable one under conditions that exist in the Charles River valley at the present time.

Adequacy of Present Sources of the Metropolitan Water District.

Bringing together the records and estimates of the consumption of water in the municipalities now constituting the Metropolitan Water District, including Newton but omitting any further provision for the city of Worcester or for other municipalities which have rights reserved for them in the watersheds from which the metropolitan water supply is derived, and have not yet exercised these rights, the following table has been prepared showing the actual consumption of water in the present district in the year 1920 and an estimate of the probable water consumption five, ten and fifteen years hence, that is, in 1925, 1930 and 1935: —

Year.	Metropolitan District, excluding Newton.		Newton.		Total.	
	Population.	Water Consumption (Gallons).	Population.	Water Consumption (Gallons).	Population.	Water Consumption (Gallons).
1920	1,206,849	127,265,000	46,054	3,687,000	1,252,903	130,952,000
1925	1,333,680	140,703,000	50,200	4,267,000	1,383,880	144,970,000
1930	1,463,870	163,661,000	54,500	4,883,000	1,518,370	168,544,000
1935	1,592,460	187,592,000	58,900	5,537,000	1,651,360	193,129,000

The estimated safe yield of all of the sources of water supply available to the Metropolitan District at the present time, as stated on page 91, is, in round numbers, 154,000,000 gallons per day. Upon comparing this figure with the actual quantity of water used daily in the year 1920, and with the estimated requirements in 1925, 1930 and 1935, as shown in the following table, it will be seen that at the estimated rate of increase in the use of water the quantity required by the district will exceed the net safe yield of the available sources of supply by about the year 1928, even if no municipality is either added to the district or exercises an existing right to take water from any source within the metropolitan watersheds. In making up this table it has been assumed that the sources of water supply of the city of Newton will be continued in use, and that the yield therefrom will be about 4,000,000 gallons per day, and that only the surplus requirements of that city will be drawn from the metropolitan water works.

Table showing a Comparison of the Yield of the Metropolitan Water Supply Sources, plus those of the City of Newton, and the Consumption of Water in the Present Metropolitan Water District in Census Years, 1920 to 1935.

	Million Gallons per Day.			
	1920.[1]	1925.	1930.	1935.
Safe yield of all metropolitan sources including Newton supply.	158.0	158.0	158.0	157.0[2]
Consumption of water in Metropolitan Water District (including Newton).	131.0	145.0	168.5	193.1
Excess	27.0	13.0	–	–
Deficiency	–	–	10.5	36.1

[1] Actual; other figures estimated.

[2] An allowance for a reduction of 1,000,000 gallons per day is made in the safe yield to provide for additional diversions of water from the metropolitan watershed and increasing losses by leakage.

This table shows that by about the year 1930 the quantity of water used in the district, on the basis of the estimates already given, may exceed the safe available yield of the sources by about 10,000,000 gallons per day.

Necessity for Immediate Action on an Additional Supply.

With years of low rainfall and a population and water consumption no greater than is herein estimated, unless a new water supply is made available by about the year 1928, serious depletion of the storage in the reservoirs will begin which, with the increasing consumption of water, will lead to their exhaustion unless an additional supply is made ready for use soon after that time. If, through the revival of business or from other cause, the consumption of water should increase more rapidly than estimated, the result would be, in years of low rainfall, an earlier and a more rapid and serious depletion of the storage reservoirs than is here indicated. Even with years of average rainfall and an increasing consumption of water, if the district continues to grow, the supply would eventually become exhausted at a date not greatly beyond the time herein indicated.

The history of the growth of population and industry in the Metropolitan Water District for many years in the past, and the constant tendency toward an increase in the consumption of water at a somewhat greater rate than the growth of population, — a tendency common to practically all cities, both in the United States and in England, — when considered in connection with the safe yield of the present sources of water supply, show clearly the necessity of increasing the water supply of the district in season to meet a greater demand than the present sources can safely be depended upon to supply after about six years.

In this estimate, as stated, no allowance is made for the taking of additional water from the district sources by any of the municipalities having rights reserved therein under various legislative acts, which have not yet exercised such right. Rights have been reserved to some 19 municipalities, but have thus far been exercised by only 9. More important, however, is the fact that no allowance is made in these calculations for furnishing water to municipalities outside the present district but within the 10-mile limit from the State House which may join the district if they so elect. There are several municipalities which are now using nearly all the water which their present sources will yield, some of which, as will be shown later, will inevitably find it necessary to secure a part of their supplies from the district, probably with the coming of the next dry period.

It is not possible to secure on short notice an adequate supply of suitable water for the additional needs of so large a district without great and wasteful expenditures upon hastily devised schemes, and without danger of serious damage to established industries. In order to devise, construct and place in operation a satisfactory additional water supply of the capacity required from any suitable source, much time will be required for legislation, for preliminary investigations, and for the preparation of plans before the work can begin, and such work is always subject to delays from various causes. The period which elapsed between the time the construction of the Wachusett Reservoir was authorized and the completion of the work was eleven years, and the period required for the construction of the reservoir alone, after work on the ground was actually begun, was nine years. The reservoir was not filled with water for the first time until thirteen years after the construction of the works was authorized, and eleven years after the construction of the reservoir was begun. In view of the nearness of the probable limit of time within which the present sources of water supply of the Metropolitan Water District will be adequate for the purpose, and considering also the time required for the actual introduction of water from any source which may be adopted, it is of the utmost importance that a scheme be selected and the work begun at the earliest practicable time.

Quality of the Water of the Present Sources of Water Supply of the Metropolitan Water District.

The water obtained from the Wachusett and Sudbury reservoirs and from Basin No. 3, and delivered to the district through the Weston Reservoir, Chestnut Hill Reservoir, and

Spot Pond, is soft, has little color, and is of excellent quality for all domestic uses. It has been affected occasionally in the past by growths of organisms which impart to the water a noticeable taste and odor. These occurrences are comparatively rare, and the tastes and odors noted in the water of the Metropolitan District since the introduction of the metropolitan water supply have been largely due to the use of water from other sources, especially Lake Cochituate, except in earlier years.

In 1909, about a year after Wachusett Reservoir was first filled, an extensive growth of the organism *Asterionella* caused the water to have a noticeable taste and odor throughout the greater part of the district, and a similar but much less objectionable condition has occurred occasionally since that time.

The water of the southern Sudbury River when used for the supply of the district is taken from Framingham Reservoir No. 2. In the upper part of this watershed are the large storage reservoirs known as the Ashland, Hopkinton and Whitehall reservoirs, all but the latter of which were thoroughly prepared for the storage of water by the removal of all the vegetation and organic matter on the area flowed. The watersheds of these reservoirs, however, contain considerable areas of swamp, and the waters entering them are quite highly colored. A considerable improvement is effected by storage in the reservoirs, but there is no means of drawing these waters for the supply of the district except by discharging them into the streams below the respective reservoirs through which the water flows to the Sudbury River and thence to Reservoir No. 2. Along the course of the Sudbury River, below the tributary reservoirs but above reservoir No. 2, there are extensive areas of swamps, and the water which enters this reservoir is usually highly colored. Its storage capacity is small, and in consequence little improvement in the quality of the water occurs in its passage through the reservoir, and if water should be drawn in any considerable quantity from this source for the supply of the Metropolitan Water District it would no doubt be objectionable, especially on account of the increase that would result in the color of the water supplied to consumers.

The water of Lake Cochituate, while not highly colored, is usually affected by the presence of large numbers of organisms and by objectionable tastes and odors, so that the mixture of even small quantities of this water with the supply delivered to the Metropolitan Water District usually causes serious complaint. Neither the waters of the southern Sudbury River nor of Lake Cochituate would be satisfactory if used in their present state for the supply of the district in connection with that of the Wachusett system, and these waters should not be used unless purified by efficient filtration.

There are still more important reasons requiring the filtration of these waters before they are used for the supply of consumers at the present time. The total population within the watershed of the Sudbury River, according to the report of the Metropolitan District Commission in 1920, was 23,033, not including a summer population of 478. A large part of this population, however, was connected with systems of sewers through which the sewage was removed from the watershed, but there was still a total population of 8,954, or 119.1 persons per square mile, not connected with the sewers. The small size of the Framingham Reservoir No. 2 affords a very inadequate protection by storage from the effect of possible pollution of the southern Sudbury waters.

The watershed of Lake Cochituate contained in 1920 a permanent population of 17,756, or 183.6 persons per square mile, of which 3,228 are not connected with the sewers; that is, the population is much greater per square mile than on the southern Sudbury River, but the large storage in the lake and its division into three basins, considered in connection with the fact that the bulk of the pollution enters at the southerly end of the lake, while the aqueduct leaves the lake near its northerly end, gives a large protection by storage under ordinary conditions. But when this lake comes to be used regularly, and large quantities of water are drawn from it, the storage will be lowered materially and the protection reduced. This water also should be filtered for the protection of the public health before it is supplied for domestic use.

The watershed of the Wachusett Reservoir contained in 1920 6,162 inhabitants, besides 1,331 temporary inhabitants in the summer season, the total permanent population being 56.6 per square mile. The population increased considerably from 1915 to 1920, and the removal of sewage from parts of this watershed will be necessary in the immediate future if serious pollution of the water supply is to be effectively prevented.

The watershed of the Sudbury Reservoir of the Wachusett system contains the city of Marlborough, but the sewage of that city is diverted for treatment to a point outside the watershed, and most of the water flowing from the populated areas of the city is filtered before it enters the reservoir.

Under the circumstances, while the filtration of the water of the Wachusett system, either for protection from danger of pollution or for the purpose of improving the quality of the water, is not a requirement of the immediate future, provided adequate means for preventing pollution are enforced, there is no doubt that filtration would improve the quality of the water and furnish an added protection to the health of the district. Sewerage works should, however, be provided in the immediate future in certain parts of the Wachusett watershed where the waters are now seriously polluted, unless other measures are adopted for the prevention of this pollution.

The water of Lake Cochituate and that of the southern Sudbury River, however, are too objectionable for use without treatment, and filtration works should be provided for the treatment of these waters as soon as their regular use becomes necessary.

Water Supply of the City of Worcester.

The city of Worcester is supplied with water from storage reservoirs on Lynde Brook in Leicester, on Kettle Brook in Leicester and Paxton, on Tatnuck Brook in Holden, and on certain tributaries of the Quinepoxet River within the watershed of the Wachusett Reservoir. The water drawn from the four storage reservoirs on Kettle Brook is diverted into Lynde Brook Reservoir by gravity and used for the supply of the high-service districts of the city. The reservoirs on Tatnuck Brook, known as Holden Reservoirs Nos. 1 and 2, are the principal sources of the water supply of the low-service system, and they have recently been supplemented with water from Kendall Reservoir, constructed within the Wachusett watershed, the water of which is diverted into the upper

Holden Reservoir known as No. 1. A larger reservoir, known as Pine Hill Reservoir, is now being constructed on the area reserved for the city of Worcester within the Wachusett watershed, the water from which will flow by gravity to Kendall Reservoir and thence to the Holden Reservoirs. The area, capacity, and the area of watershed of each of the reservoirs now in use or under construction for the water supply of the city of Worcester are shown in the following table: —

Reservoir.	Elevation [1] (Feet).	Area of Reservoir (Square Miles).	Total Storage Capacity (Million Gallons).	Area of Watershed, including Reservoir (Square Miles).
Kettle Brook No. 4	1,082.74	.186	514	1.805
Kettle Brook No. 3	1,040.00	.058	152	.722
Kettle Brook No. 2	988.50	.048	127	.569
Kettle Brook No. 1	845.36	.007	19	1.002 [2]
Lynde Brook	822.94	.206	701	2.921
Upper Holden	750.88	.211	794	4.555
Lower Holden	718.80	.089	283	.676
Kendall	814.00	.273	850	2.451
Pine Hill	910.00	.720	3,000	6.899
Totals	–	1.798	–	21.600

[1] Above mean sea level. [2] Includes Peter Brook.

The safe yield of the present sources of water supply of the city of Worcester is about 16,000,000 gallons per day, but with the completion of the Pine Hill Reservoir this yield will be increased to 19,300,000 gallons per day, as estimated by the engineers of the city. The consumption of water in the city in 1920 was 16,515,000 gallons per day, and the safe yield of the Worcester sources, including Pine Hill Reservoir, will be reached, at the rate of increase in consumption of water maintained for many years in the past, within the next five years.

The city of Worcester has grown steadily and quite rapidly for many years, having doubled in population since 1891. The city adopted the meter system many years ago, and for the last twenty-six years more than 90 per cent of the services have been metered. The increase in the consumption of water per capita since 1900 has been at the rate of 1.16 gallons per head per year. Allowing that the rate of increase in the population in the future will be less than in the past, and that it will require forty-five years for the population to become double what it is to-day, and allowing for an increase in the per capita daily consumption of about 0.9 of a gallon per person per year, the quantity of water required in the future will be about as shown in the following table: —

Estimated Population and Water Consumption of the City of Worcester, 1920–1970.

	Population.	Per Capita Consumption (Gallons).	Total Consumption (Gallons).
1920[1]	179,754	91.9	16,515,000
1925	198,500	96.8	19,215,000
1930	217,500	101.6	22,098,000
1935	237,000	106.2	25,169,000
1940	257,100	111.0	28,538,000
1945	277,800	115.5	32,086,000
1950	298,000	120.1	35,790,000
1955	318,800	124.3	39,627,000
1960	339,600	128.6	43,673,000
1965	360,000	132.8	47,808,000
1970	380,700	137.0	52,156,000

[1] 1920 figures actual; others estimated.

In the foregoing table no allowance is made for the probability that water will eventually be supplied from the city of Worcester to some of the adjacent towns which now obtain their water supplies from independent sources.

An investigation for an additional supply of water for the city of Worcester has been made under authority of chapter 176 of the Special Acts of the year 1918, which was passed in response to a petition by the city of Worcester, and a report was presented to the Legislature of 1920, which is printed as Senate Document No. 346 of that year. That report presents in some detail the results of studies of many sources of water supply in the region about Worcester, and recommends that the city be authorized to take an additional supply from Quinepoxet Pond and a neighboring stream, tributaries of the Quinepoxet River, which is one of the main feeders of the Wachusett Reservoir. The watersheds from which the city desires to take water have an area of about 17.4 square miles, or 15.9 per cent of the area remaining tributary to Wachusett Reservoir after the diversion of the watersheds of the Pine Hill and Kendall reservoirs provided for in the original Metropolitan Water Act.

The estimated cost of the various plans considered as sources of additional water supply for Worcester is given in the above-mentioned report as follows: —

Estimates of Cost.

Early in the report it was stated that satisfactory estimates are impossible under the present conditions of labor, scarcity and high prices of coal and other materials and equipment. This is especially true because much of the work will be deferred for a number of years, when it is probable that more normal conditions will obtain. The scarcity of labor has been felt by the city in carrying on current work, and this would be aggravated by starting immediately on any large program of construction. However, to reach a decision, estimates have been prepared for the Quinapoxet project (No. 1), for the project which involves taking Stiles Reservoir and Cedar Meadow Pond (No. 2), and for the Five Mile River project (No. 3), which involves taking and enlarging Stiles Reservoir for storage only and filling it from the Five Mile River source. In these estimates the current high prices for construction have been used, and also water damages above the average paid in the past.

Quinapoxet Project (No. 1).

The first cost of obtaining water from the Quinapoxet source and delivering it to both high and low service, including works and damages as outlined on pages 20 to 23, is estimated to amount to $833,000.

It is estimated that a dam at Gray's Mill, with its top at elevation 800, with appropriate works for stream control during and after construction, including the expense of purchasing and improving the site of the reservoir, with a flow line at elevation 790, would cost in the neighborhood of $1,050,000. Such a reservoir would not appear necessary until 1940.

Stiles Reservoir–Cedar Meadow Pond Project (No. 2).

The initial works necessary for bringing water from Stiles Reservoir to the city of Worcester involve a concrete conduit to Lynde Brook Reservoir, a connection from Cedar Meadow Pond to Stiles Reservoir, and the drainage of the large swamp on its watershed. These works, together with the cost of acquisition and the damages for diversion of water, are estimated to amount to $2,250,000.

In about 1935 it will probably be found desirable to raise the level of Stiles Reservoir to elevation 873, and thereby develop its great storage capacity as a safeguard to the city of Worcester against a dry period. The cost of the dam and dikes, together with the improvement of the area to be flowed, is estimated at present prices to be about $2,370,000.

Not many years after the construction of the reservoir it will probably be necessary to bring in water from a new source — presumably the Five Mile River — to maintain the reservoir full.

Five Mile River Project (*No. 3*).

The necessary works to deliver water to the city of Worcester from the Five Mile River at Lake Lashaway include the enlargement of Stiles Reservoir, the concrete conduit from there to Lynde Brook Reservoir, the improvement of the swamp above Stiles Reservoir, and the building of a pumping station at Lake Lashaway with a force main and channels to carry the water over the divide and deliver it into Stiles Reservoir. The estimated cost of this project, including the cost of acquiring the Stiles Reservoir site and the damages from the taking of Lake Lashaway, Brooks Pond and the flows of the Five Mile River for the months of January to May, inclusive, of each year, amounts to $4,700,000.

An increased pumping capacity or a large storage reservoir would be necessary in about 1940. The cost of such storage reservoir and a pipe line to connect it with the pumping station at Lake Lashaway at present prices is estimated to be $1,100,000.

For a final comparison of these schemes there should be added to the Quinapoxet supply the sum of $460,000, which, assumed to be set aside in 1925 at 4½ per cent interest, would pay for all future pumping of the amount of water which could be furnished by gravity from the drainage areas of Stiles Reservoir and Cedar Meadow Pond. Similarly, $980,000 should be added to the ultimate cost of the Lake Lashaway project.

The present sources of water supply of Worcester are drawn from sparsely populated watersheds, and the water supplied from them, though affected sometimes by growths of organisms which occasionally reach sufficient numbers to cause objectionable tastes and odors, is soft and nearly colorless and of good quality for domestic use. So far as can be judged at the present time, these reservoirs are likely to continue to furnish water of suitable quality for the supply of the city for many years in the future. Additional sources will have to be provided, however, in the immediate future to meet the growing needs of the city, and the situation of the city of Worcester is, therefore, very similar in the matter of water supply to that of the Metropolitan Water District. Each has nearly reached the limit of capacity of its present water supply, and each in the near future must incur a large expenditure to meet its rapidly growing needs.

The investigations made by the engineers of the city of Worcester indicate clearly that the cost of works for supplying water to that city from Quinepoxet Pond would be less than from any other source investigated. Judging from the obvious practical advantages of such a plan, it appears probable that a mutually satisfactory arrangement eventually will be made whereby the city of Worcester will in the future obtain its additional water supply from the watersheds of or in connection with the Metropolitan Water District.

Effect upon the Water Supply of the Metropolitan Water District if the City of Worcester were granted the Right to take an Additional Supply from the Wachusett Watershed.

In a previous table (on page 82) only the water supply needs of the Metropolitan Water District as at present constituted have been considered. If the petition of the city of Worcester for the right to take water from a portion of the Wachusett watershed should be granted, the water supply of the Metropolitan Water District would be depleted at a more rapid rate than is indicated in the previous table. With the completion of the Pine Hill Reservoir the city of Worcester will have developed all of its available sources of water supply to their fullest practicable capacity, and their yield will probably be sufficient to meet the requirements of the city, so far as can now be foreseen, for at least five years. Assuming that after that time any deficiency in the city's supply will be met from the metropolitan watersheds, the safe yield of these watersheds plus the safe yield of the sources of water supply of the city of Worcester will be about as shown in the following table: —

	Gallons.
Safe yield of sources of supply of the Metropolitan Water District with allowance for various losses	154,000,000
Estimated safe yield of the sources of water supply of the city of Newton	4,000,000
Estimated safe yield of the sources of water supply of the city of Worcester	19,300,000
Total safe yield of sources of water supply of the Metropolitan Water District, including the cities of Newton and Worcester	177,300,000

A comparison of this total safe yield with the actual consumption of water in the Metropolitan Water District, including the city of Newton, and in the city of Worcester, in 1920, with the estimated water consumption in 1925, 1930 and 1935, is shown in the following table: —

	Million Gallons per Day.			
	1920.[1]	1925.[2]	1930.[2]	1935.[2]
Safe yield of metropolitan sources, including Newton and Worcester.	177.3	177.3	177.3	176.3
Consumption of water in Metropolitan District, plus Newton and Worcester.	147.5	164.2	190.6	218.3
Excess of safe yield over consumption of water . .	29.8	13.1	–	–
Deficiency of safe yield compared with estimated consumption of water.	–	–	13.3	42.0

[1] Consumption figures actual. [2] Consumption figures estimated.

The results presented in this table indicate that with the addition of the city of Worcester the sources of the Metropolitan Water District would be more rapidly depleted than would otherwise be the case, and the storage in the reservoirs would become exhausted at a somewhat earlier date.

Probable Requirements of Cities and Towns within 10 Miles of the State House not at Present included in the Metropolitan Water District.

The legislation providing for a metropolitan water supply, chapter 488, Acts of 1895, contains the following provisions relative to the municipalities to be supplied with water under that act: —

Section 3. Said board, acting for the Commonwealth, shall construct, maintain and operate a system of metropolitan water works substantially in accordance with the plans and recommendations of the state board of health, contained in their report to the legislature of the year eighteen hundred and ninety-five, and shall provide thereby a sufficient supply of pure water for the following named cities and towns, and the inhabitants thereof, to wit: — The cities of Boston, Chelsea, Everett, Malden, Medford, Newton and Somerville, and the towns of Belmont, Hyde Park, Melrose, Revere, Watertown and Winthrop, which cities and towns shall constitute the Metropolitan Water District; shall secure and protect the purity of said water; shall on application furnish water to any city or town aforesaid that at the time of application owns its water pipe system; shall on application admit any other city or town, any part of which is within ten miles of the state house, into said water district, and furnish water to the same on the terms prescribed by this act for the cities and towns aforesaid, and on such payment of money as said board may determine; shall on application furnish water to any water company owning the water pipe system in any town within said ten miles, on such water company assuming the assessments of the town, if any, and making such payment of money as said board may determine; and may from time to time furnish water to any other city, town or water company, on such payment of money as said board may determine. . . .

Since the passage of the above act the city of Quincy and the towns of Arlington, Lexington, Milton, Nahant, Stoneham and Swampscott have been admitted to the district, while the town of Hyde Park has been annexed to the city of Boston and disappears as a separate municipality. In addition to the towns which originally constituted or have since joined the Metropolitan Water District, there remain 16 cities and towns within the 10-mile limit which, the act requires, shall on application be admitted to the district and supplied with water under the terms prescribed in the act. These municipalities are the following: Lynn, Saugus, Wakefield, Woburn, Winchester, Cambridge, Waltham, Brookline, Wellesley, Needham, Dedham, Canton, Braintree, Weymouth, Hingham and Hull.

Of these municipalities the city of Cambridge and the town of Brookline lie wholly within the geographical limits of the Metropolitan Water District as now constituted, while each of the remaining municipalities is adjacent to its present boundaries. The population of each of these cities and towns in census years since 1870 is shown in the following table: —

Population of 16 Municipalities within 10 Miles of the State House which, under the Provisions of the Metropolitan Water Act, shall on Application be admitted to the Metropolitan Water District and supplied with Water therefrom.

	1870.	1875.	1880.	1885.	1890.	1895.	1900.	1905.	1910.	1915.	1920.
Cambridge	39,634	47,838	52,669	59,658	70,028	81,643	91,886	97,434	104,839	108,822	109,694
Brookline	6,650	6,675	8,057	9,196	12,103	16,164	19,935	23,436	27,792	33,490	37,748
Wellesley[1]	-	-	-	3,013	3,600	4,229	5,072	6,189	5,413	6,439	6,224
Needham[1]	3,607	4,548	5,252	2,586	3,035	3,511	4,016	4,284	5,026	6,542	7,012
Canton	3,879	4,192	4,516	4,380	4,538	4,636	4,584	4,702	4,797	5,623	5,945
Braintree	3,948	4,156	3,855	4,040	4,848	5,311	5,981	6,879	8,066	9,343	10,580
Weymouth	9,010	9,819	10,570	10,740	10,866	11,291	11,324	11,585	12,895	13,969	15,057
Hingham	4,422	4,654	4,485	4,375	4,564	4,819	5,059	4,819	4,965	5,264	5,604
Hull	261	316	383	451	989	1,044	1,703	2,060	2,103	2,290	1,771
Wakefield	4,135	5,349	5,547	6,060	6,982	8,304	9,290	10,268	11,404	12,781	13,025
Woburn	8,560	9,568	10,931	11,750	13,499	14,178	14,254	14,402	15,308	16,410	16,574
Lynn	28,233	32,600	38,274	45,867	55,727	62,354	68,513	77,042	89,336	95,803	99,148
Saugus	2,247	2,578	2,625	2,855	3,673	4,497	5,084	6,253	8,047	10,226	10,874
Winchester	2,645	3,099	3,802	4,390	4,861	6,150	7,248	8,242	9,309	10,005	10,485
Waltham	9,065	9,967	11,712	14,609	18,707	20,876	23,481	26,282	27,834	30,154	30,915
Dedham	7,342	5,756	6,233	6,641	7,123	7,211	7,457	7,774	9,284	11,043	10,792
Totals	133,638	151,115	168,911	190,611	225,143	256,218	284,887	311,651	346,418	378,204	391,448

[1] Wellesley set off from Needham April 6, 1881.

The quantity of water used by each of these cities and towns in census years since 1900, so far as records are available, is shown in the following table. Estimates of the consumption have been made where records are not available, and wherever the figures are estimates they are so noted.

Population and Consumption of Water of 16 Municipalities within 10 Miles of the State House, 1900–20.

	1900.			1901.			1902.			1903.			1904.			1905.			1906.		
	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).
Cambridge	91,886	79.0	7,304	92,996	83.0	7,690	94,105	86.0	8,099	95,215	91.0	8,642	96,324	92.0	8,847	97,434	92.0	8,973	98,915	96.0	9,491
Brookline	19,935	97.0	1,941	20,635	92.0	1,902	21,335	92.0	1,961	22,036	96.0	2,116	22,736	103.0	2,348	23,436	95.0	2,228	24,307	84.0	2,048
Wellesley	5,072	47.0	239	5,295	46.0	244	5,519	47.0	257	5,742	51.0	294	5,966	52.0	313	6,189	47.0	289	6,034	45.0	273
Needham	4,016	56.0	224	4,070	57.0	231	4,123	67.0	275	4,177	71.0	295	4,230	65.0	274	4,284	66.0	284	4,432	77.0	342
Canton[1]	4,584	46.0	209	4,608	43.0	197	4,631	49.0	226	4,655	55.0	254	4,678	62.0	288	4,702	63.0	296	4,721	49.0	230
Braintree	5,981	91.0	544	6,161	78.0	479	6,340	85.0	538	6,520	88.0	574	6,699	88.0	592	6,879	87.0	600	7,116	77.0	549
Weymouth[2]	11,324	–	610	11,376	–	630	11,428	–	650	11,481	–	670	11,533	–	690	11,585	–	700	11,848	–	720
Hingham[3]	5,059	50.8	257	5,011	51.5	258	4,963	52.2	259	4,915	52.8	260	4,867	53.5	260	4,819	54.1	261	4,848	54.7	265
Hull[3]	1,703	145.0	247	1,774	146.8	260	1,846	148.5	274	1,917	150.2	288	1,989	152.0	302	2,060	153.8	317	2,069	155.5	322
Wakefield[4]	9,290	60.0	557	9,500	60.0	570	9,681	60.0	577	9,877	60.0	588	10,072	65.0	655	10,268	73.0	747	10,495	69.0	729
Woburn	14,254	78.0	1,117	14,284	78.0	1,120	14,313	83.0	1,193	14,343	94.0	1,351	14,372	98.0	1,413	14,402	103.0	1,490	14,583	104.0	1,513
Lynn, Saugus (combined)	73,597	64.0	4,680	75,537	60.0	4,506	77,476	60.0	4,684	79,416	65.0	5,138	81,355	66.0	5,333	83,295	59.0	4,924	86,113	60.0	5,133
Winchester[5]	7,248	–	225	7,447	–	240	7,646	–	250	7,844	–	255	8,043	–	260	8,242	–	270	8,455	–	280
Waltham	23,481	90.0	2,118	24,041	95.0	2,291	24,601	99.0	2,435	25,162	90.0	2,254	25,722	81.0	2,073	26,282	79.0	2,070	26,592	73.0	1,941
Dedham	7,457	79.0	586	7,520	83.0	621	7,584	89.0	675	7,647	104.0	796	7,711	135.0	1,041	7,774	135.0	1,046	8,076	95.0	770
Totals	284,887	73.2	20,858	290,255	73.2	21,239	295,591	75.6	22,353	300,947	79.0	23,775	306,297	80.6	24,689	311,651	78.6	24,495	318,604	77.2	24,606

[1] 1913 and 1920 water consumption figures estimated. [2] All water consumption figures estimated, except 1915–20, inclusive.
[3] Water consumption figures estimated. [4] 1900 and 1901 water consumption figures estimated. [5] All water consumption figures estimated, except 1918 and 1919.

Population and Consumption of Water of 16 Municipalities within 10 Miles of the State House, 1900–20 — Continued.

	1907.			1908.			1909.			1910.			1911.			1912.			1913.		
	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).
Cambridge	100,396	109.0	10,992	101,877	103.0	10,450	103,358	95.0	9,859	104,839	100.0	10,458	105,636	97.0	10,226	106,432	101.0	10,793	107,229	98.0	10,549
Brookline	25,178	89.0	2,236	26,050	90.0	2,353	26,921	86.0	2,314	27,792	89.0	2,476	28,932	90.0	2,605	30,071	88.0	2,633	31,211	87.0	2,708
Wellesley	5,879	52.0	305	5,723	54.0	310	5,568	58.0	324	5,413	61.0	331	5,618	63.0	354	5,823	64.0	374	6,029	65.0	389
Needham	4,581	69.0	315	4,729	75.0	355	4,878	69.0	335	5,026	66.0	332	5,329	58.0	308	5,632	63.0	356	5,936	58.0	344
Canton	4,740	51.0	244	4,759	59.0	280	4,778	60.0	287	4,797	61.0	293	4,962	65.0	323	5,127	75.0	386	5,293	64.0	338
Braintree	7,354	66.0	484	7,591	56.0	424	7,829	63.0	493	8,066	81.0	653	8,321	63.0	524	8,577	68.0	587	8,832	62.0	545
Weymouth	12,109	–	740	12,371	–	770	12,633	–	790	12,895	–	810	13,110	–	840	13,325	–	870	13,539	–	900
Hingham	4,877	55.4	270	4,907	56.0	275	4,936	56.7	280	4,965	57.3	284	5,025	57.9	291	5,085	58.6	298	5,144	59.2	304
Hull	2,077	157.2	327	2,086	159.0	332	2,094	160.8	337	2,103	162.5	342	2,140	164.2	351	2,178	166.0	362	2,215	167.8	372
Wakefield	10,722	68.0	724	10,950	67.0	730	11,177	62.0	698	11,404	61.0	694	11,679	57.0	664	11,955	60.0	713	12,230	56.0	684
Woburn	14,764	114.0	1,682	14,946	111.0	1,652	15,127	119.0	1,803	15,308	139.0	2,134	15,528	120.0	1,856	15,749	128.0	2,014	15,969	109.0	1,744
Lynn, Saugus	88,930	68.0	6,018	91,748	67.0	6,118	94,565	68.0	6,394	97,383	72.0	7,027	99,112	68.0	6,710	100,841	67.0	6,750	102,571	62.0	6,366
Winchester	8,669	–	290	8,882	–	300	9,095	–	310	9,309	–	325	9,448	–	340	9,587	–	350	9,727	–	360
Waltham	26,903	84.0	2,272	27,213	83.0	2,266	27,524	87.0	2,382	27,834	88.0	2,443	28,298	89.0	2,513	28,762	95.0	2,743	29,226	93.0	2,714
Dedham	8,378	104.0	868	8,680	109.0	947	8,982	129.0	1,160	9,284	129.0	1,202	9,636	128.0	1,235	9,988	116.0	1,156	10,339	108.0	1,121
Totals	325,557	85.3	27,767	332,512	82.9	27,562	339,465	81.8	27,766	346,418	86.0	29,804	352,774	82.6	29,140	359,132	84.6	30,385	365,490	80.5	29,438

Population and Consumption of Water of 16 Municipalities within 10 Miles of the State House, 1900–20 — Concluded.

	1914.			1915.			1916.			1917.			1918.			1919.			1920.		
	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).
Cambridge	108,025	94.0	10,137	108,822	82.0	8,957	108,996	89.0	9,711	109,171	89.0	9,712	109,345	102.0	11,127	109,520	96.0	10,513	109,694	104.2	11,435
Brookline	32,350	89.0	2,875	33,490	82.0	2,750	34,342	83.0	2,838	35,193	87.0	3,078	36,045	87.0	3,144	36,896	90.0	3,309	37,748	91.4	3,451
Wellesley	6,234	64.0	398	6,439	73.0	470	6,396	78.0	498	6,353	86.0	544	6,310	86.0	545	6,267	83.0	522	6,224	86.1	536
Needham	6,239	63.0	395	6,542	62.0	405	6,636	62.0	413	6,730	56.0	379	6,824	68.0	462	6,918	57.0	396	7,012	64.2	450
Canton	5,458	53.0	291	5,623	56.0	313	5,687	53.0	301	5,752	51.0	296	5,816	68.0	395	5,881	75.0	439	5,945	70.5	419
Braintree	9,088	60.0	549	9,343	53.0	498	9,590	65.0	625	9,838	60.0	588	10,085	72.0	722	10,333	62.0	637	10,580	70.1	742
Weymouth	13,753	–	930	13,969	69.0	966	14,187	65.0	918	14,404	78.0	1,127	14,622	99.0	1,445	14,839	81.0	1,208	15,057	97.0	1,464
Hingham	5,204	59.9	312	5,264	60.5	318	5,332	61.1	326	5,400	61.8	334	5,468	62.4	341	5,536	63.1	349	5,604	63.7	357
Hull	2,253	169.5	382	2,290	171.2	392	2,186	173.0	378	2,082	174.8	364	1,979	176.5	349	1,875	178.2	334	1,771	180.0	319
Wakefield	12,506	47.0	590	12,781	46.0	592	12,830	48.0	619	12,879	43.0	554	12,927	61.0	786	12,976	45.0	584	13,025	47.6	620
Woburn	16,190	116.0	1,883	16,410	122.0	1,996	16,443	136.0	2,229	16,476	124.0	2,046	16,508	141.0	2,320	16,541	109.0	1,796	16,574	127.0	2,104
Lynn, Saugus	104,300	65.0	6,761	106,029	60.0	6,385	106,828	66.0	7,065	107,626	68.0	7,316	108,425	77.0	8,374	109,223	74.0	8,048	110,022	82.8	9,113
Winchester	9,866	–	380	10,005	–	395	10,101	–	410	10,197	–	430	10,293	42.0	435	10,389	43.0	444	10,485	45.0	472
Waltham	29,690	83.0	2,465	30,154	76.0	2,294	30,306	75.0	2,258	30,458	74.0	2,249	30,611	82.0	2,510	30,763	63.0	1,952	30,915	63.4	1,960
Dedham	10,691	99.0	1,054	11,043	88.0	973	10,993	92.0	1,008	10,943	95.0	1,041	10,892	104.0	1,133	10,842	73.0	796	10,792	74.0	799
Totals	371,847	79.1	29,402	378,204	73.3	27,704	380,853	77.7	29,597	383,502	78.4	30,058	386,150	88.3	34,086	388,799	80.6	31,327	391,448	87.5	34,211

While the cities and towns included in the foregoing table, with the exception of Cambridge and Brookline, are outside the boundaries of the Metropolitan Water District and have not grown in population in the past at the same rate as the district as a whole, their situation is such with respect to the district that they are likely to increase in population somewhat more rapidly in the future than in the past. Furthermore, many are important manufacturing municipalities which are likely to have a considerable growth from that cause alone. Estimates of the future population of these cities and towns, together with their probable water supply requirements, are shown in the following table: —

Population and Consumption of Water of 16 Municipalities within 10 Miles of the State House, 1920–70.

	1920.[1]			1925.			1930.			1935.			1940.			1945.		
	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).
Cambridge	109,694	104.2	11,435	118,000	108.0	12,744	126,800	111.5	14,138	135,000	114.8	15,498	142,500	117.9	16,801	149,500	120.8	18,060
Brookline	37,748	91.4	3,451	43,750	94.7	4,143	50,000	98.0	4,900	56,200	101.3	5,693	62,500	104.6	6,538	68,700	107.9	7,413
Wellesley	6,224	86.1	536	6,800	89.5	609	7,400	92.9	687	8,000	96.3	770	8,600	99.7	857	9,200	103.0	948
Needham	7,012	64.2	450	7,700	68.4	527	8,500	72.6	617	9,200	76.8	707	10,050	81.0	814	10,950	85.2	933
Canton	5,945	70.5	419	6,650	74.0	492	7,400	77.0	570	8,200	80.0	656	9,000	83.0	747	9,900	86.0	851
Braintree	10,580	70.1	742	11,800	73.5	867	13,070	77.0	1,006	14,370	80.5	1,157	15,770	84.0	1,325	17,170	87.5	1,502
Weymouth	15,057	97.0	1,464	16,700	100.0	1,670	18,500	103.0	1,906	20,400	106.0	2,162	22,400	109.0	2,442	24,500	112.0	2,744
Hingham	5,604	63.7	357	5,993	67.0	402	6,382	70.1	447	6,768	73.3	496	7,160	76.5	548	7,542	79.8	602
Hull	1,771	180.0	319	2,520	189.1	477	2,835	198.0	561	3,195	207.0	661	3,600	216.0	778	4,050	225.0	911
Wakefield	13,025	47.6	620	14,200	52.6	747	15,400	57.6	887	16,600	62.6	1,039	17,800	67.6	1,203	19,200	72.6	1,394
Woburn	16,574	127.0	2,104	17,300	133.0	2,301	18,100	139.0	2,516	18,900	145.0	2,741	19,800	151.0	2,990	20,700	157.0	3,250
Lynn, Saugus	110,022	82.8	9,113	123,000	86.4	10,627	132,000	89.6	11,827	140,000	93.0	13,020	149,000	96.4	14,364	157,000	99.7	15,653
Winchester	10,485	45.0	472	11,600	50.0	580	12,700	55.0	699	13,800	60.0	828	14,930	65.0	970	16,100	70.0	1,127
Waltham	30,915	63.4	1,960	33,200	71.5	2,374	36,000	79.0	2,844	38,900	85.5	3,326	41,600	91.5	3,806	44,100	96.5	4,256
Dedham	10,792	74.0	799	12,000	85.0	1,020	13,200	92.5	1,221	14,500	98.0	1,421	15,800	102.5	1,620	17,200	106.5	1,832
Totals	391,448	87.5	34,241	431,213	91.8	39,580	468,287	95.7	44,826	504,033	99.5	50,175	540,510	103.2	55,803	575,812	106.8	61,476

[1] 1920 figures actual; others estimated.

Population and Consumption of Water of 16 Municipalities within 10 Miles of the State House, 1920–70 — Concluded.

	1950.			1955.			1960.			1965.			1970.		
	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).
Cambridge	156,000	123.5	19,266	162,000	126.1	20,428	168,000	128.6	21,605	174,000	131.0	22,794	180,000	133.5	24,030
Brookline	74,900	111.2	8,329	81,100	114.4	9,278	87,300	117.6	10,266	93,600	120.8	11,307	99,700	124.0	12,363
Wellesley	9,900	106.0	1,049	10,600	109.0	1,155	11,300	112.0	1,266	12,000	114.5	1,374	12,800	117.0	1,498
Needham	11,800	89.4	1,055	12,800	93.6	1,198	13,700	97.8	1,340	14,750	101.9	1,503	15,700	106.0	1,664
Canton	10,800	89.0	961	11,800	92.0	1,086	12,750	95.0	1,211	13,700	98.0	1,343	14,700	101.0	1,485
Braintree	18,600	91.0	1,693	20,050	94.5	1,895	21,500	98.0	2,107	22,970	101.5	2,331	24,520	105.0	2,575
Weymouth	26,600	115.0	3,059	28,700	118.0	3,387	30,800	121.0	3,727	32,900	124.0	4,080	35,000	127.0	4,445
Hingham	7,939	82.9	658	8,328	86.1	717	8,717	89.3	778	9,106	92.5	842	9,495	95.6	908
Hull	4,500	234.0	1,053	4,950	243.0	1,203	5,445	252.0	1,372	5,940	261.0	1,550	6,435	270.0	1,737
Wakefield	20,600	77.6	1,599	22,000	82.6	1,817	23,400	87.6	2,050	24,800	92.6	2,296	26,250	97.6	2,562
Woburn	21,600	163.0	3,521	22,500	169.0	3,803	23,400	175.0	4,095	24,300	181.0	4,398	25,200	187.0	4,712
Lynn, Saugus	166,000	103.1	17,115	174,000	106.4	18,514	183,000	109.9	20,112	191,000	113.4	21,659	200,000	116.8	23,360
Winchester	17,250	75.0	1,294	18,420	80.0	1,474	19,600	85.0	1,666	20,800	90.0	1,872	22,000	95.0	2,090
Waltham	47,000	101.0	4,747	49,800	105.0	5,229	52,400	108.5	5,685	55,000	111.5	6,133	58,000	114.5	6,641
Dedham	18,600	109.5	2,037	20,000	112.5	2,250	21,500	115.0	2,473	23,000	117.5	2,703	24,700	120.0	2,964
Totals	612,089	110.2	67,436	647,048	113.5	73,434	682,812	116.8	79,753	717,866	120.1	86,185	754,500	123.3	93,034

Water Supply of the City of Cambridge.

The water supply of the city of Cambridge was taken originally from Fresh Pond in Cambridge in 1856. This supply was supplemented in 1887 with water brought in a conduit from a storage reservoir constructed on Stony Brook, a tributary of the Charles River, in Waltham and Weston, known as the Stony Brook Reservoir. In 1897 a larger storage reservoir, separated into two parts and known as the Upper and Lower Hobbs Brook Reservoirs, was completed on Hobbs Brook, a tributary of Stony Brook, in Waltham, Lincoln and Lexington. The water from the Hobbs Brook Reservoirs flows in the channel of Hobbs Brook to Stony Brook Reservoir, and is drawn through a conduit to Fresh Pond, whence it is pumped for the supply of the city. The area and capacity of Fresh Pond and of the storage reservoirs on Stony Brook, together with the area of the watershed of each, are shown in the following table: —

Reservoir.	Area in Square Miles, Water Surface.	Available Capacity in Million Gallons.	Elevations[1] referred to. High Water.	Elevations[1] referred to. Low Water.	Area of Watershed in Square Miles.
Upper Hobbs	.14	241.4	181.0	-	7.25
Lower Hobbs	.73	2,097.4	181.0	-	
Stony Brook	.12	406.0[2]	83.0	61.0	16.32
	.11	354.0	81.0	61.0	
Fresh Pond	.25	400.0	17.0	9.0	1.25
	-	770.0[3]	17.0	3.0	

[1] Elevations refer to Cambridge city base. Subtract 4.98 feet to convert to Boston city base.

[2] Approximate. Flashboards have recently been placed on the spillway of Stony Brook Reservoir, and this capacity has not been used heretofore.

[3] This capacity is not available, as 9.0 is considered by Cambridge authorities the lowest level to which Fresh Pond can be drawn.

The amount of water obtainable at the present time from Stony Brook and Fresh Pond is limited by the capacity of the conduit connecting these sources, which was estimated several years ago to have a capacity of 11,375,000 gallons per day. The safe yield of present sources of water supply was estimated by Mr. F. P. Stearns, consulting engineer, in a report to the city of Cambridge dated October 26, 1911, as 11,500,000 gallons per day. The increased storage caused by raising Stony Brook Reservoir 2 feet has increased the safe yield of all sources to about 11,700,000 gallons per day. The consumption of water in the city of Cambridge in the year 1920 was 11,435,000 gallons per day, or an amount nearly equal to the safe yield of the Cambridge water works as at present developed.

Limitations of Enlargement of Cambridge Supply.

In the original plans for increasing the water supply of Cambridge by the taking of Stony Brook, surveys were made of various reservoir sites all of which have now been utilized with the exception of a site suggested in the valley of Cherry Brook in Weston. This site, however, is near the village of Weston, and the construction of a reservoir in this locality is not now deemed practicable.

Various other schemes for enlarging the water supply of Cambridge have been considered, including raising the level of Fresh Pond, raising the level of Stony Brook Reservoir, and finally the utilization of the water wasted below the Stony Brook Reservoir dam in the winter and spring months by pumping that water back to Hobbs Brook Reservoir in dry periods, since the latter reservoir has a storage capacity so large in proportion to its watershed that it will not fill in years of low rainfall at the present rate of water consumption. The plan of raising Fresh Pond was rejected by the consulting engineers in 1912 as of doubtful practicability within reasonable limits of cost. It was estimated at the same time that the raising of the dam of Stony Brook Reservoir 20 feet would give an increase in yield about equal to that which might be obtained by raising Fresh Pond 12 feet if that work could be completed successfully, and the capacity of the Stony Brook Reservoir if raised 20 feet would be increased from 354,000,000 to 1,112,000,000 gallons. It was estimated that this scheme if adopted would increase the safe yield of all the sources of water supply of the city to 13,600,000 gallons per day, with allowance of 500,000 gallons a day for the probable loss of water by leakage past the Stony Brook dam. By the third plan considered by the engineers, which provided for pumping back the water wasting from Stony Brook Reservoir into Hobbs Brook in dry periods, it was estimated that the safe yield of the sources of supply could be increased to about the same quantity as would be obtained by raising the dam at Stony Brook Reservoir, and at about half the cost.

The results of the studies of the consulting engineers of the city of Cambridge in 1912 show clearly that the safe yield of the present sources of water supply cannot be increased, unless at excessive cost, to more than about 13,600,000 gallons per day. The consumption of water in the city is already almost equal to the safe yield of the sources of supply as at present developed, and at the present rate of increase the use of water in the city will reach the capacity of the works at their highest practicable development about the year 1928. In making this estimate, allowance has been made for the fact that the growth of Cambridge in the last ten years has been slow, and it is assumed that the growth will continue at about the same rate in the future. There is considerable uncertainty, however, about the probable growth of population in Cambridge on account of the fact that shortly before the war a subway was completed providing rapid transit from a large part of the city of Boston, which may encourage a more rapid growth of population in the immediate future.

While nearly half of the service pipes in Cambridge are metered at the present time, and reliance is placed upon inspection to prevent excessive use and waste of water from unmetered services, it is believed that the amount of water used could be reduced by the general adoption of the meter system. Considering the efforts to prevent waste, and the fact that there is a very large use of water in the city for industrial purposes, it is doubtful, however, whether any very material reduction would be made by the addition of meters to unmetered services, though the complete metering of the services of the city would no doubt effect a saving in the use of water.

Much water used in the industries of Cambridge is obtained from private wells, but it is unlikely that the amount of water obtained in this way can be very materially increased in the future, and in consequence the increase in the use of water for industrial purposes must come largely from the public supply. It is possible, however, that water for some purposes can be taken from the Charles River Basin.

The water supply of the city of Cambridge as drawn from Fresh Pond has been objectionable on account of organic growths and the tastes and odors resulting therefrom, and there has been a gradual increase in population on the watershed of Stony Brook which lies close to the Metropolitan District, and that watershed is likely to become more populous as time goes on. The city has recently undertaken the construction of filters, and it is expected that in future all the water supplied to the city will be treated by filters located near Fresh Pond.

Various possible sources of further additional supply have been considered by the city, but the results indicate that no source is available which can supply water as economically as the Metropolitan Water District. There appears to be no doubt that the city of Cambridge must be supplied from the Metropolitan Water District with water to meet its requirements beyond the capacity of the present sources fully developed, probably within the next eight years.

An additional supply could be furnished by the Metropolitan District under the provisions of chapter 422 of the Acts of the year 1913, entitled "An Act relative to allowances to cities and towns in the Metropolitan Water District for water furnished from their own sources." Under such an arrangement it is assumed that the present sources of supply could be continued in use for many years.

Water Supply of the Town of Brookline.

The water supply of the town of Brookline, like that of the city of Newton, is drawn from ground sources by means of galleries and tubular wells, which in this case are located on both sides of the Charles River in the neighborhood of Cow Bay, part of the works being in the West Roxbury district of the city of Boston and part within the limits of the town of Dedham. The works are all included within a water works reservation of some 295 acres, of which about 66 acres are on the West Roxbury side of the river. A filter gallery located near the northerly bank of the river in West Roxbury was the original source of water supply. In later years systems of tubular wells have been constructed on land lying south of the river between the high lands of Dedham Island and the southerly boundary of the Newton water works reservation. More recently the supply has been supplemented with water pumped from Charles River to filter beds near the filter gallery, whence it filters through the ground into the gallery and wells. The mixed supply from the wells and filter gallery is subsequently filtered before being supplied to the town.

The limitations as to the taking of water from Charles River by the town of Brookline are the same as those imposed by the Legislature in the case of the city of Newton, and reduce practically the quantity of water that may be drawn from either the ground or the river itself in dry periods to 5,000,000 gallons per day. With allowance for periods of maximum draft, the practical limit of the amount of water that may be drawn from present works operated alone is about 3,750,000 gallons per day in dry periods, but, as in the case of the city of Newton, a larger supply, probably in the neighborhood of 4,000,000 gallons per day, could be drawn from these works if the town should join the Metropolitan Water District under the provisions of chapter 422 of the Acts of the year 1913.

The quality of the water of the Brookline water supply has deteriorated gradually from various causes, including the growing population on the territory in the immediate neighborhood of the collecting works in West Roxbury and Dedham, and the increasing pollution of Charles River, from which a large part of the yield of these sources is undoubtedly derived. It became so objectionable on account of the presence of an excessive quantity of iron and manganese that filters were constructed some five years ago, and since that time all the water supplied to the town has been treated for the removal therefrom of the excess of iron and manganese, and filtered.

The population of the town of Brookline has grown steadily and rapidly for many years, having increased from 12,103 in 1890 to 37,748 in 1920. In that time the use of water has increased from 877,000 to 3,451,000 gallons per day, or nearly fourfold. Practically all of the water services in this town have been metered for many years. The consumption per capita has usually been high, notwithstanding the fact that for many years all of the services have been metered, and there will probably continue to be a gradual increase in the consumption of water per capita in the future. With the continued growth of population and increase in the use of water, the consumption of water by the town is likely to exceed the safe yield of the sources of supply under the limitations of existing laws within the next five or six years.

It is impracticable to extend further the limits of the present water works reservation, nor is it likely that further grants for water supply from the valley of the Charles River can be obtained by any of the municipalities now taking water in the lower part of its watershed, unless provision should be made for the construction of storage reservoirs in the watershed above to maintain the flow of the stream in dry periods. It is doubtful whether suitable reservoirs for this purpose can be constructed in the Charles River watershed within a reasonable limit of cost, even if joint action on the part of all the municipalities interested in the water supply from this river could be secured.

Under the circumstances, it seems reasonable to assume that the town of Brookline will take advantage of the provisions of chapter 422 of the Acts of the year 1913, if a mutually satisfactory arrangement can be made, and thus obtain an additional water supply from the Metropolitan Water District: The town can then continue to use its present sources of supply to their full extent so long as their use is satisfactory.

Water Supply of the City of Waltham.

The water supply of the city of Waltham is taken from the ground by means of two large wells located on the northerly side of the Charles River in Waltham, — the lower one about 1¼ miles upstream from the Boston Manufacturing Company's dam at Moody Street in the heart of the city, and the other about three-fourths of a mile farther upstream. The lower well is located about 150 feet from the channel of the river which at this point is about 18 feet in depth. This well is 40 feet in diameter and contains normally 25 feet of water, its bottom being below the bed of the river. The upper well, also on the north bank of the river, is located about 300 feet from the river channel. The latter well is 30 feet in diameter and its bottom is about 33 feet below the average level of the water in the river. There is a large deposit of coarse sand and gravel along the northwesterly side of the river, beginning near the lower well and continuing upstream to the upper well and through the district known as Roberts along the easterly side of the Stony Brook Basin of the Cambridge water works. This water-bearing area is about three-fourths of a mile long and from one-fourth to one-half a mile in width. On the south side of the river there are additional areas containing porous soil of about the same extent, including the Crescent Park district in Waltham and also certain lands in the extreme northwesterly corner of Newton. The gravelly water-bearing areas occupy in all perhaps 300 acres, or about half a square mile of tributary area, including the area of the river bottom itself in the neighborhood of the wells. The city of Waltham owns or controls all of the land in the immediate vicinity of the wells and an extensive strip on the north bank of the river extending from the lower well for a considerable distance upstream.

The city of Waltham has the right to take 5,000,000 gallons of water per day from the Charles River watershed, 3,000,000 from the river direct or from the ground bordering the river, and the other 2,000,000 from the ground bordering the river. The supply obtained by these works, like that obtained by the city of Newton and much of the supply of the town of Brookline, is derived in part no doubt from the rainfall upon the gravelly deposits in which the collecting works are located, and in part from the Charles River by filtration through the ground. In the critical winter of 1918 the daily draft rose to 44 per cent above the average of that year. Judging from past experience, it is probable that the works are capable of a safe yield of between 2,500,000 and 3,000,000 gallons of water per day. It is possible that by extending the collecting works and building additional works near the outer rim of the area affected by pumping from the old well a larger quantity of water might be obtained, but it is exceedingly doubtful whether the dry-weather flow of the river will long continue to meet the demands of all the manufactories and municipalities having a right to take water therefrom and allow for a greater average draft for the city of Waltham than from 3,500,000 to 4,000,000 gallons per day. In estimating for the future, the possibility that the diversion of water from the Charles River at points in and above Waltham will increase materially must also be taken into account. In dry seasons the river is drawn to a low level in the neighborhood of Waltham, and measurements of the flow of the river at different points indicate that at times nearly all of the yield of that portion of the watershed between Newton Upper Falls and the Bleachery dam in Waltham is diverted from the river before it reaches the latter point. This diversion is doubtless caused in several ways, chief among which are the evaporation from large areas of water surface in mill ponds between Newton Upper Falls and the Bleachery, the removal of water by filtration through the ground into the water supply systems of Wellesley and Waltham, the diversion of water from the river for use in manufactories whence it is discharged into the sewers, and finally the leakage of ground and surface water into the sewerage systems, which are very extensive in this part of the Charles River valley.

The quality of the water of the old well, the original source of water supply, situated at the lower end of the water works reservation, is affected unfavorably, and in an increasing degree at the present time, by the presence of an excessive quantity of iron and manganese which make the water objectionable for many domestic uses, and if deterioration continues, as is probable unless the draft from this well is very greatly reduced, the water will soon become unfit for many water supply purposes. The quality of this water is unfavorably affected, also, by the large and growing population on the watershed of the well, by the municipal cemetery which immediately adjoins the land in which the lower collecting well is constructed, by the numerous mud and peat covered areas in the adjacent mill pond, and finally by the increasing pollution of the Charles River above the wells from which a large part of the supply is no doubt derived by filtration through the ground. It is only by reducing the draft from the lower well and maintaining the water at a much higher level than has been the case for many years hitherto that a supply of water unaffected by the presence of an excessive amount of iron can be obtained; and even if the draft should be greatly reduced, it is doubtful whether, after the excessive draft for so long a period, satisfactory water could be obtained from that source without treatment and filtration. The water also contains considerable free carbonic acid which causes it to act on the metal of pipes and fixtures with which it comes in contact.

The upper well furnishes water of much better quality than that of the lower well at the present time. The supply of the upper well is no doubt derived in part by filtration from the adjacent gravelly lands and in part by filtration from the river, but its yield is probably also maintained to a very considerable extent by leakage or filtration past the dam of the Stony Brook Reservoir of the Cambridge water works situated a short distance above the well. When the water in the Stony Brook Reservoir is low the latter source of supply to the well is diminished.

The population of Waltham has doubled since 1886, and the quantity of water used has increased since 1890 from 626,000 gallons per day to 1,960,000 gallons per day in 1920. The consumption of water at one time was much higher than at present, but the recent general introduction of meters, by which practically all of the services are metered, has materially reduced the use of water, though a part of this reduction is doubtless due to serious depression in industry. In estimating for the future, it has been assumed that the rate of growth of the city will be somewhat less than in the past, and that the increase in the use of water per person will be considerably less than in the last thirty years. It is probable that the effect of the introduction of meters has been fully obtained, and that within the next few years an increase in consumption of water per capita will again take place in common with experience elsewhere. If, as it is assumed, the city will go to the expense of purifying its water supply by the construction and maintenance of filters similar in a general way to those at Brookline, Lowell, and elsewhere, it is probable that enough water can be obtained from present sources to last the city for the next ten to fifteen years. Without treatment the quality of the water of the lower well, which is already objectionable for many domestic uses, is likely to continue to grow worse.

The Waltham water works reservation is not capable of further material extension, being limited in an easterly direction by the thickly settled part of the city, and toward the west by the water works reservation of the city of Cambridge. It is also impracticable to extend the collecting works farther north materially beyond the limits of the present reservation, while to the south are populous districts in Waltham and Newton. In view of the cost of filtration works and of their maintenance, and considering the comparatively short period within which the sources of supply are likely to be adequate for the city, it is probable that a supply of water could be obtained from the Metropolitan Water District at less cost than by further development of the present works.

It will probably be to the advantage of this city to join the Metropolitan Water District, under the provisions of chapter 422 of the Acts of the year 1913, and to continue to use the water of the upper well. It may also be possible to continue to use the lower well for a part of the supply, provided that by reducing the draft a water of satisfactory quality can be obtained from that source. If the lower well can be used without filtration the two wells might furnish 1,500,000 gallons per day of good water in a very dry period. If not, the upper well alone might furnish about 1,000,000 gallons per day if used in connection with the metropolitan water supply system.

Water Supply of the City of Woburn.

The water supply of the city of Woburn is taken from a large dug well near the southerly shore of Horn Pond, and from tubular wells on the westerly side of the pond. Water is pumped from the pond into the old filter gallery about 73 feet from the large well for the purpose of increasing the supply of ground water. The safe yield of these sources is insufficient for the requirements of the city in periods of drought at the present time.

The question of an additional supply has been mentioned in reports of the water department for several years, but no action has been taken to secure a suitable additional supply. The high yields of watersheds of the past few years, due to the unusual rainfall, especially in the summer season, has enabled the city to continue to obtain an adequate water supply from present sources. Investigations made many years ago indicated clearly that the yield of the present sources of supply is derived very largely from Horn Pond by filtration through the ground to the wells, and the amount of water obtainable from the present sources is no doubt dependent to a very considerable extent upon the yield of Horn Pond and its watershed. The area of Horn Pond is 103 acres, and the area of the watershed, including the pond, is 7.44 square miles. With certain assumptions as to the storage capacity available in Horn Pond and in the porous ground around it, it is possible that by utilizing all of the water obtainable from the pond itself, together with the wells, the safe yield of these sources might amount to about 2,400,000 gallons per day, assuming that the water obtained in this way would be satisfactory for domestic purposes. Horn Pond, however, is exposed to pollution from a large population on its watershed, and at times in the past has been grossly polluted by wastes from manufacturing establishments. The water of the pond is too badly polluted at the present time for use with safety without thorough purification, and any proposition to develop a further supply from this watershed by filtering the water from Horn Pond would require a large outlay for the construction and maintenance of purification works.

The population of Woburn has increased but little for many years, the increase in the last thirty years having been from 13,499 to 16,574, but in that period the use of water has increased from 777,000 to 2,104,000 gallons per day. The city is quite thoroughly metered, but the consumption of water per capita is high, largely because large quantities of water are used in the industries of the city, chiefly tanneries and chemical works. As these industries are growing and the establishments are increasing in number, there is little doubt that the use of water will increase materially in the future, depending more or less upon the general industrial prosperity.

If the entire supply which could be obtained by filtering the polluted water of Horn Pond were used in connection with water from the filter gallery, large well and tubular wells, the increase in the safe capacity of present sources would hardly exceed by more than 15 per cent the consumption of water in 1920. It would be inadvisable for the city to attempt to secure an additional supply by the use of water from Horn Pond, since the cost of the works would be out of proportion to the amount of water that could be obtained thereby. A new supply is already needed for this city and should be provided without delay. In all probability by far the least expensive method of securing a suitable water supply would be a connection with the Metropolitan Water District, under the provisions of chapter 422, Acts of the year 1913.

The water obtained from the wells, while affected considerably by mineral matter due to the population in the neighborhood and to the pollution of Horn Pond from which this supply is largely derived, has always been safe for drinking, and, save for its hardness, of good quality for water supply purposes. The use of this water can probably be continued at least for some time in the future, and the wells can probably be relied upon to yield on an average about 1,500,000 gallons per day in dry periods, if used in connection with the metropolitan water supply. The sources are situated quite near the thickly populated part of the city, however, and it is doubtful whether the quality of the water can long be maintained in satisfactory condition for water supply purposes if the lands from which the supply is derived become considerably populated, or if further material deterioration occurs in the quality of the water of Horn Pond.

Water Supply of the Town of Wellesley.

The population of Wellesley in 1920 was 6,224, having about doubled since 1885. The town is the seat of Wellesley College and is largely residential, though it contains also a number of manufacturing establishments. The water supply is obtained from a filter gallery, a large well at Williams Spring and tubular wells in the valley of Rosemary Brook, not far from the point where that stream enters Charles River. The water of the tubular wells, which were added to the other sources about 1898, is of good appearance, and though quite hard is in other respects of good quality for domestic use. The water of the well at Williams Spring is also of good appearance, though much harder than that of the tubular wells. Much of the water entering this well has been polluted, but subsequently well purified in passing through the ground before entering the well. The water of the filter gallery is similar to that of the other sources, being less hard than that of the Williams Spring. The waters of all the sources of supply show decided deterioration in the marked increase of mineral content in recent years derived probably from the growing population on the territory about the wells.

The quantity of water obtainable from these sources of supply as at present developed has been found sufficient for the present requirements of the town, and it is possible that the yield of the works could be enlarged somewhat by the addition of other wells in this neighborhood farther up Rosemary Brook, but the region is becoming increasingly populated, and it is doubtful whether a supply of water of good quality can long be maintained in this locality.

The quantity of water used for the supply of the town in 1920 was 536,000 gallons per day, or 86 gallons per inhabitant, the use of water having more than doubled in twenty years, though practically all of the services have been metered for nearly thirty years.

While thorough tests of the probable yield of these sources are lacking, the circumstances are such that it is doubtful if the works can be extended so that the supply will continue to be adequate and satisfactory for the requirements of the town for more than ten years, and it may prove insufficient or unsatisfactory at an earlier time.

When an additional supply is required it will probably be necessary to take water from the Metropolitan Water District, though the present sources or a part of them may continue to be used so long as they furnish water of a good quality acceptable to the town.

Water Supply of the Town of Needham.

The population of Needham in 1920 was 7,012. The town has had a steady growth and has about doubled in size in the last twenty-five years. It is largely a suburban town, though it contains a number of important manufacturing establishments. The average daily quantity of water used for the supply of the town in 1920 was 450,000 gallons per day, amounting to about 64 gallons per inhabitant. Practically all of the services have been metered at all times during the past twenty years; nevertheless, the water consumption has doubled during that period.

The sources of supply are two large wells in the southeasterly part of the town in the valley of a brook about 2,000 feet from the Charles River. A basin holding some 9,000,000 gallons, constructed on the stream in the valley of which the wells are located, assists in maintaining the water level in the ground near the wells. Nevertheless, in dry periods the quantity of water which these sources will yield is probably inadequate for the present requirements of the town. The water of the present sources of supply is clear, colorless, and much lower in hardness than most of the ground water supplies obtained in the Charles River valley. The gathering ground of these works is located quite close to the thickly populated part of Needham, but the town owns a considerable area of land in the neighborhood of the wells for the protection of its sources of water supply, and it is probable that the water can be maintained in its present condition for a number of years in the future.

Recognizing the probable need of extending the collecting works in the future, the town several years ago purchased land near the banks of Charles River with a view to the construction of additional wells for increasing the water supply when necessary. No extended test has yet been made to determine whether a suitable additional supply can be obtained within these lands or elsewhere within the limits of the town when a larger supply becomes necessary.

A considerable area of land in the region bordering the Charles River on the northeasterly side of the town has been acquired by the city of Newton and by the town of Brookline, and is used as a gathering ground for the water supplies of those municipalities. There are places along the Charles River, above the region in which the present wells are situated, where porous soil is found, and it is possible that a further additional supply can be obtained in this region when a larger quantity of water is required. Should the town continue to grow rapidly in the future, however, it is likely eventually to find it necessary to obtain a part of its supply from the Metropolitan Water District.

Water Supply of the Town of Dedham.

The population of Dedham in 1920 was 10,792. The population was reduced several years ago by the setting off of Westwood as an independent town, and, allowing for this change, the population of Dedham has doubled in about forty years. The town is the county seat of Norfolk County, and is largely residential, but contains a considerable manufacturing district.

The water supply is furnished by the Dedham Water Company and is derived from a group of wells, including three large wells and a group of tubular wells near by, all being located near the southerly bank of Charles River above and very close to the thickly settled portion of the town. The water is clear and colorless and of excellent appearance, and has always been of satisfactory quality for domestic use. It is quite hard and contains a considerable amount of mineral matter, a condition which is due, no doubt, to the population on the territory from which a large part of the supply is derived. The quantity of water used by the town in 1920 was 799,000 gallons per day, or 74 gallons for each inhabitant. About 95 per cent of the services are metered, and the introduction of meters has reduced considerably the consumption of water per capita, though the amount used still varies considerably, with variations in the amount supplied for industrial uses.

The quantity of water which the sources of water supply of the Dedham Water Company will yield in a dry period has not been definitely determined, but it is probable that their safe yield is not greatly in excess of the quantity of water used in 1920. The water company has the right to take 1,500,000 gallons per day from Charles River. No extended investigations have been made as to a possible extension of the supply when the consumption of water becomes equal to the capacity of the present sources. There are areas of porous soil adjacent to the river upstream from the wells, in regions which are as yet sparsely populated and from which it is possible that an additional supply of ground water might be obtained if these areas continue to remain available for a sufficient length of time. It is probable that the present sources can be supplemented if necessary, so that they will be adequate for a number of years in the future unless the population and use of water should increase more rapidly than it now seems reasonable to expect.

Water Supply of the Town of Winchester.

Winchester contained in 1920 a population of 10,485, the population having doubled in about thirty years. It is a suburban town with comparatively little manufacturing, and the quantity of water used in 1920 was probably about 472,000 gallons per day, or about 45 gallons per inhabitant. All of the services are metered.

The present sources of water supply consist of three reservoirs known as the North, South and Middle reservoirs, which are located in the high lands in the eastern part of the town near the western limits of the Middlesex Fells. From these reservoirs the water is supplied to the greater part of the town by gravity. The watersheds have an aggregate area of 1.25 square miles, of which 0.31 of a square mile is included in the surfaces of the reservoirs. The total storage capacity is 993,000,000 gallons, and the reservoirs are capable of storing so much water in proportion to their drainage area that practically the average yield of the watersheds over a long period of years can be obtained. This yield may amount to about 700,000 gallons per day, allowing for losses of water by leakage and evaporation, or approximately 50 per cent in excess of the present consumption of water in the town. If the town continues to grow about as in the past, the present sources of supply will be sufficient for the next ten years at least.

The North Reservoir was built in 1873 and appears to have received no more preparation for the storage of water than the clearing of the ground. When first examined by the State Department of Health, fourteen years after its completion, the water of this reservoir contained considerable organic matter, though it was low in color and generally of good quality for domestic uses. The quantity of organic matter has decreased in later years, but the water is affected occasionally by growths of organisms and the tastes and odors which result therefrom.

The South Reservoir was completed about twenty-eight years ago. Like the North Reservoir, it received no more thorough preparation for the storage of water than the clearing of the land. In consequence, in the early years after its completion the water had a high color and contained usually a large amount of organic matter. The quality of the water since that time has improved gradually, and is now nearly colorless, while the quantity of organic matter is very low.

The Middle Reservoir was formed by flooding an area known as Turkey Swamp, and, while its watershed is small, there is an overflow from the Middle Reservoir into the South Reservoir. The water of the Middle Reservoir after its construction contained a very large quantity of organic matter for many years, and the color was high. The quality of this water also, however, has improved greatly, though the color is still from two to three times as great as that of the water of the other reservoirs.

The watersheds of the Winchester reservoirs are uninhabited and are included in a public reservation.

Water Supply of the Town of Wakefield.

The population of Wakefield in 1920 was 13,025, the number of inhabitants having doubled in about thirty-five years. The consumption of water in 1920 was 620,000 gallons per day, or 48 gallons per inhabitant. All of the services have been metered since 1915.

The water supply is drawn from Crystal Lake in Wakefield, which has an area of 85 acres, a drainage area of 0.9 of a square mile, and a storage capacity in the upper 10 feet of something over 200,000,000 gallons. The watershed contains a large population in proportion to its size, and the town has been warned by the Department of Public Health that the water of Crystal Lake is unsafe for drinking. The water is at present treated with chlorine. The quantity of water which this source will yield amounts to about 750,000 gallons per day, and exceeded the consumption of water in 1920 by from 20 to 25 per cent. If the town continues to grow as in the past, the consumption of water will equal the safe yield of the present sources in about five years.

It has been proposed to take an additional water supply, when needed, from Lake Quannapowitt in Wakefield, one of the headwaters of the Saugus River. This lake receives all of the drainage of the thickly settled part of Reading, and the drainage from a part of the most populous area in Wakefield. A considerable amount of sewage pollution finds its way into the lake. The lake is shallow over a considerable portion of its area, has a muddy bottom, and contains an exceedingly productive and increasing growth of water weeds in summer. The water could be used for domestic water supply only after filtration, and the drawing down of the level of the lake, which would be necessary if it were used as a source of water supply for the town, might produce more objectionable conditions from organic growths and in other ways than those complained of up to the present time. The lake is used extensively as a place of public recreation, but if used as a source of water supply its availability as a place of recreation would be greatly restricted or cease altogether. It is probable that the town will find it necessary to obtain its water supply from the Metropolitan Water District within a few years.

Water Supply of the City of Lynn and the Town of Saugus.

The population of Lynn in 1920 was 99,148, and that of Saugus, 10,874, a total of 110,022.

The population of Lynn and Saugus has nearly doubled in the last thirty years. The quantity of water used for the supply of these municipalities from the Lynn sources has increased in that time from 2,657,000 to 9,084,000 gallons per day. In 1920 64 per cent of the services were metered, and the consumption of water per capita at the present time is not excessive, though meters are soon to be applied to the remaining services.

A large part of the area of the city of Lynn is included in the public park known as the Lynn Woods, and is consequently not available for settlement. The population upon the area available for building within the limits of the city is already quite dense, and it is probable that the growth of the city will be less rapid in the future than in the past. The town of Saugus, on the other hand, is likely from its situation to continue to grow rapidly.

The water supply of the city of Lynn is obtained at the present time from storage reservoirs known as Breed's, Birch, Walden and Hawkes ponds, and may be supplemented with water drawn during a part of each year from the Saugus and Ipswich rivers. The area, capacity, and area of direct tributary watersheds of these sources are shown in the following table: —

Area and Capacities of Sources of Water Supply of the City of Lynn.

Source.	Area of Watershed (Square Miles).	Area of Pond (Square Miles).	Storage Capacity (Million Gallons).
Ipswich River above point of diversion	43.12	-	-
Saugus River above point of diversion	10.58	-	-
Breed's Pond	1.07	.325	1,600
Walden Pond	1.75	.375	2,000
Birch Pond	.68	.128	381
Hawkes Pond	1.86	.117	350
Totals	59.06	.945	4,331

As the watersheds of the reservoirs lie for the most part within the limits of the Lynn Woods, a public park, they contain as a rule few dwelling houses or other buildings. The watershed of the Saugus River, however, contains the densely populated section of the town of Reading and a large section of the more densely populated parts of Wakefield, and in consequence receives much pollution.

The watershed of the Ipswich River, from which Lynn takes water at a point about a mile above the dam at South Middleton, is not very densely populated at any point at the present time. There has been, however, a considerable growth of population within this watershed in Wilmington and Burlington, and as this watershed is not far from the Metropolitan District the population may be expected to increase in the future.

The water of the Saugus River flows by gravity to Hawkes Pond, whence most of it is pumped to Walden Pond. The water of the Ipswich River is pumped into Walden Pond and thence diverted to Breed's Pond, from which it flows to the main pumping station and is pumped thence for the supply of the city. The water of Birch Pond, which is supplied in part from Hawkes Pond, flows directly to the main pumping station.

The rights of the city of Lynn in the Ipswich River authorize the taking of all the flow of that river at a point where it crosses the boundaries of Lynnfield, North Reading and Middleton in excess of 10,000,000 gallons per day, but only in the months from December to May, inclusive.

The water of the Saugus River is very highly colored, and the chemical analyses show evidence of increasing pollution due to the population on its watershed. The water is considerably improved by storage in Hawkes Pond and a portion of the color is removed. This water is pumped into Walden Pond which also receives water from the Ipswich River during the winter and spring, the water of the latter source also being very highly colored, though much less objectionable in other respects than that of the Saugus River. The color of the water of Walden Pond averaged 0.47 on the scale of color in the five years which ended with 1920, while that of Breed's Pond, into which this water is discharged, averaged 0.37 in that period. Birch Pond has a considerable population on its watershed, and though its color has been reduced in the five years ending with 1920, it has averaged during this period 0.22. The population on its watershed is a menace to the safety of this source of supply, but this pond now furnishes a comparatively small portion of the water supply of the city.

Under normal conditions, with the present rate of consumption of water, the water of the Saugus and Ipswich rivers has to pass through a long period of storage before being delivered to consumers in the city. In consequence, the waters of these streams are improved in quality and their high color reduced. As the use of water from the storage reservoirs increases with the growth of the city, the period of storage in the reservoirs will diminish in length and the improvement in the quality of the water due to storage will diminish. Where polluted rivers form the main source of supply, as in this case, unless further means of protecting the purity of the water are to be provided, a sufficient amount of water must be kept in storage at all times to insure such improvement in the quality of the water as will prevent it from becoming unsafe for drinking or objectionable for other domestic uses.

Assuming that it will require more than fifty years before the populations of the city of Lynn and the town of Saugus will become double what they are to-day, and that the consumption of water will continue to increase slowly within that time, the safe yield of all of the present sources of supply will probably be sufficient for the requirements of the city of Lynn and the town of Saugus for more than thirty years. If, instead of dependence upon long storage for the purification of the water, a system of filtration should be provided, a greater proportion of the storage in the reservoirs could be utilized and the sources of supply would be adequate for a longer time. If, on the other hand, on account of its objectionable quality and serious pollution, the use of Saugus River should be discontinued, the length of time during which the supply would be adequate would be considerably reduced. Further development of the present watersheds or other watersheds adjacent to the water supplies of the city of Lynn is probably impracticable unless at a very large expense.

Water Supply of the Town of Canton.

The population of Canton in 1920 was 5,945. The town has grown very slowly in the past, having gained about 32 per cent in population in the last forty years. Though formerly chiefly a manufacturing town, it is now also becoming largely a place of suburban residence.

The sources of supply are two large wells situated in the valley of Beaver Brook, the first located near Springdale, not far from the boundary line between Canton and Stoughton, and the second at Henry's Spring, so called, about 1.5 miles farther up the valley. In addition to the large wells there are 19 tubular wells at Springdale which siphon into the large Springdale well. The well at Springdale furnishes water which is generally clear, nearly colorless, and of good quality for domestic use. The water of the well at Henry's Spring is at times turbid and colored and affected by an excess of iron. The quantity of water used for the supply of the town in 1919 was 439,000 gallons per day, or 75 gallons per inhabitant. The quantity used ten years earlier was 287,000 gallons, or 60 gallons per inhabitant. More than 80 per cent of the services are metered. The quantity of water furnished by present sources has been found in past years to be barely adequate for the requirements of the town, and investigations as to an additional supply have failed thus far to discover any source capable of furnishing a large additional quantity of suitable water for the use of the town. The question of securing water in the future from the Metropolitan Water District has been under consideration by the authorities of the town.

Water Supply of the Town of Braintree.

The population of Braintree in 1920 was 10,580. The town is growing quite rapidly and has doubled in size in the last twenty-six years. The population is largely residential, though there are a number of factories within its limits, and on account of its situation it is likely to have a steady growth, both in manufacturing and as a place of residence.

The water supply of the town is taken from Great Pond in Randolph and Braintree, which is also used as a source of water supply by the towns of Randolph and Holbrook, each town having the right to one-third of the supply from that source. Great Pond has an area at high water of 205 acres and a watershed of about 3.47 square miles, including the area of the pond, and, with certain assumptions as to its available storage capacity, its safe yield probably does not exceed 1,500,000 gallons per day. The watershed of Great Pond contains a large population in proportion to its area, and the source is not considered a safe one from which to take water directly for drinking. The water at times is highly colored and in its present condition objectionable in many respects for domestic use.

The quantity of water used in the town of Braintree in 1920 was 742,000 gallons per day, or 70 gallons per inhabitant. The amount used in 1913 was 545,000 gallons, or 62 gallons per inhabitant. During this period 92 per cent of the services have been metered. It will be noted that the quantity of water used by the town is already in excess of its share of the yield of Great Pond. There appears to be no source from which it is practicable to enlarge the water supply of Braintree at reasonable expense except by connection with the Metropolitan Water District, and it is understood that negotiations relative to securing a water supply from the district have already been begun. There is no doubt, under the existing conditions, that the most satisfactory method by which Braintree can obtain an adequate water supply of good quality is by joining the Metropolitan Water District.

Water Supply of the Town of Weymouth.

The population of Weymouth in 1920 was 15,057. The growth of the town for many years was very slow. Recently it has grown more rapidly, the increase having been about thirty per cent in the last fifteen years. The town contains a number of factories and a considerable summer population along the shore of Boston Harbor, and is likely from its location to have a steady growth in the future.

The source of water supply is Great Pond, situated in the southerly part of the town. The pond has an area of 300 acres, a drainage area of 2.5 square miles, and, with certain assumptions as to its storage capacity, its safe yield probably does not exceed 1,700,000 gallons per day. With the present rate of increase in the population and the use of water, the consumption of water in the town will equal the safe yield of Great Pond in about five years. There appears to be no other source of water supply in this region from which it is practicable to secure a satisfactory additional water supply for

Weymouth, and negotiations have already been begun by the town for the purpose of making connection with the Metropolitan Water District.

The water of Great Pond is highly colored, and its character has changed but little since it was first used for water supply purposes. Probably the use of this source would be discontinued if a supply of water of better quality should be made available for the use of the inhabitants of the town at a reasonable cost.

Water Supply of the Towns of Hingham and Hull.

The towns of Hingham and Hull lie partly within the 10-mile limit prescribed in the Metropolitan Water Supply Act of 1895, and may enter the Metropolitan Water District if they so elect. The population of Hingham in 1920 was 5,604, the population having increased somewhat less than 25 per cent in the previous thirty years. The town of Hull in 1920 had a population of 1,771, having increased some 80 per cent in the last thirty years. Though containing only a very small number of permanent residents in 1920, this town is one of the largest summer resorts on the Massachusetts coast, containing many thousands of visitors during the months of July and August. The population of Hingham is almost wholly residential and is also increased during part of the year by summer residents, especially along the harbor shores.

These towns are supplied with water by the Hingham Water Company, and it is estimated that during the year 1920 the average daily quantity of water used was about 676,000 gallons. The sources of supply are Accord Pond in Hingham and Rockland, together with Fulling Mill Pond in Hingham, and a ground-water supply from wells and filters located near the latter pond, this last-named supply being supplemented with water drawn from Accord Brook and discharged upon the ground in the neighborhood of the collecting works. The area of the ponds and watersheds from which the supply is derived is shown in the following table: —

	Area of Watershed, including Water Surface (Square Miles).	Area of Pond (Square Miles).	Approximate Capacity of Pond (Gallons).
Accord Pond	.70	.15	482,424,000
Fulling Mill Pond	.39	.02	-
Accord Brook	3.12[1]	-	-

[1] Exclusive of Accord Pond watershed.

The water supplied from Accord Pond is low in color and of good quality in all respects for domestic use. The water supplied from the ground-water collecting works is also naturally of good quality for domestic use. The region is a difficult one in which to obtain water of satisfactory quality for domestic purposes, but the present sources can probably be developed sufficiently to meet the requirements of these towns until their population becomes considerably greater than at the present time.

Probable Requirements of Towns which are Outside the 10-Mile Limit which may require a Supply from the Metropolitan Water District.

There are several towns which do not come within the 10-mile limit specified in the Metropolitan Water Act but which may desire, for one reason or another, within a few years to obtain their water supply from the Metropolitan Water District, under the provisions of section 3 of the Metropolitan Water Act (chapter 488, Acts of 1895). These towns are the following: Weston, Reading, Norwood, Westwood, Randolph, Holbrook, Cohasset and Scituate.

The aggregate population of these towns in 1920 was 36,796. The population has grown slowly, for the most part, though much more rapidly in recent years, and the conditions in some of these towns make a new or improved water supply a necessity of the immediate future. The conditions in each will here be briefly described.

Water Supply of the Town of Weston.

The town of Weston — population in 1920, 2,282 — at present obtains its water supply from wells in Cherry Brook valley in that town, together with other wells near Stony Brook within the watershed from which the Cambridge water supply is drawn. It is possible that this town may at no distant date desire to secure its water supply from the Metropolitan Water District, since the Weston Aqueduct passes through the town and the Weston Reservoir is situated within its limits, so that the town could readily be supplied from these sources if it should so desire.

Water Supply of the Town of Reading.

The population of Reading in 1920 was 7,439. The town is largely residential, though containing a number of factories. The water supply is obtained from a filter gallery and wells located near the Ipswich River in the northerly part of the town. The water as drawn from the ground is very objectionable for domestic uses on account of the presence of an excessive amount of iron, and for many years this water has been treated with chemicals and subsequently filtered before being supplied to consumers. The water as drawn from the ground has deteriorated greatly in quality since it was first used, due to an increasing pollution of the river above the wells and other causes, but this condition has improved somewhat recently, due in part to improvements in the watershed and no doubt in part to a higher rainfall. As delivered to consumers in 1920, the water was generally somewhat colored and slightly turbid. It also contained at times a large amount of iron and was very hard, so that even the treated water is still objectionable for many domestic uses.

Extensive tests have failed to disclose a source from which a more desirable water supply can be obtained within the limits of the town.

The quantity of water used in 1920 was 287,000 gallons per day, or 39 gallons per inhabitant. Over 90 per cent of the services have been metered for the last fifteen years, and the increase in the use of water per inhabitant in that time has been on the average nearly a gallon per head per year. A sewerage system has recently been constructed, and it is probable that the use of water in the future will be greater than has been the case in the past. It is hardly probable that the town will long continue to use water of the character supplied from its present sources should a supply of water of better quality become available at a reasonable cost.

Water Supply of the Town of Norwood.

The population of Norwood in 1920 was 12,627, or more than three times as great as in 1890. The rapid growth of the town is due to the location of several large industries within its limits within the past few years. The water supply was obtained originally from Buckmaster Pond in Westwood which was later supplemented with water from tubular wells in the valley of Purgatory Brook, a tributary of the Neponset River in the northeasterly part of the town. The water of Buckmaster Pond is filtered in the summer season through an uncovered sand filter for the removal of objectionable taste and odor with which the water is sometimes affected, a condition due to the presence of numerous microscopic organisms at certain seasons of the year, the growth of which is no doubt fostered by a deposit of organic matter on the bottom of the pond. The water of the tubular wells has deteriorated greatly in quality, and the aggregate yield of all sources has recently become inadequate and is. now (1921) being supplemented by the introduction of water from an additional group of tubular wells on the northerly side of the valley of Purgatory Brook.

The quantity of water used by the town in 1920 was 1,191,000 gallons per day, or 94 gallons per inhabitant. Over 80 per cent of the services are metered, but the quantity of water used has more than doubled in the last ten years. It is hardly likely that the present sources of supply will meet the needs of the town in a very dry year when its industries are operating at normal capacity, and a further additional supply will very soon be required. There are extensive deposits of porous material in the valley of the Neponset River which borders the town for a long distance, but the river is badly polluted, and it is doubtful whether a satisfactory additional water supply can be obtained within the limits of the town. It is probable that when the next deficiency in the supply occurs the town will find it desirable to secure its water supply, if practicable, in part at least from the Metropolitan Water District.

Water Supply of the Town of Westwood.

This town lies between Dedham and Norwood and was set off from the town of Dedham a little more than twenty years ago. Its population in 1920 was 1,358, and the town is not yet provided with a public water supply, though water is distributed from a private supply to a considerable number of dwelling houses in the easterly part of the town. There is little doubt that some provision will have to be made by the town for a general public water supply in the near future. The quantity of water which would be required in the beginning would not be large, and it is possible that enough might be obtained for a time from sources within the limits of the town. The population is likely to grow rapidly, however, and eventually the town is likely to find it necessary to secure water either from the sources of one of its neighbors or from the Metropolitan Water District in case circumstances should make it practicable to obtain a supply from the latter source at a reasonable cost.

Water Supply of the Towns of Randolph and Holbrook.

The population of Randolph in 1920 was 4,756, and that of Holbrook, 3,161. Both towns have grown slowly though somewhat more rapidly in recent years than formerly. They obtain their water supply from Great Pond in Randolph and Braintree, which is used jointly by the three towns of Randolph, Holbrook and Braintree. Randolph and Holbrook are supplied through the same general works, and used together, in 1919, 454,000 gallons per day, or 58 gallons per inhabitant. This quantity of water is less than half of that part of the yield of Great Pond to which Randolph and Holbrook are entitled under legislative acts, and, considering the slow growth of these towns, the safe yield of Great Pond is unlikely to be exhausted by their requirements alone for many years. As already indicated in considering the water supply of Braintree, the watershed of Great Pond contains a large and growing population, especially in the immediate neighborhood of the pond, and the conditions are such that the water in its present state cannot be regarded as safe for drinking. Either an extensive system of sewerage will have to be provided to maintain proper sanitary conditions in this watershed, or the water will have to be filtered if this source is to continue in use. The expense of improving and maintaining the quality of the water will be large, and it is probable that if a suitable arrangement could be made for taking water from the Metropolitan Water District it would be to the advantage of the towns to take water from that source rather than incur the expense of filtration or the adequate protection of the purity of the water of Great Pond by other means.

Water Supply of the Town of Cohasset.

The population of Cohasset in 1920 was 2,639. The town is almost wholly residential and the permanent population has increased but little for many years, but there is a large increase in the summer season which does not appear in census enumerations. In consequence, the town uses for several months in summer a much larger quantity of water than is required for the remainder of the year.

The water supply is furnished at the present time by the Cohasset Water Company from several distinct sources. Part of it is purified by filtration, as in the case of Reading, in order to remove the excessive quantity of iron which it contains before it is delivered to consumers. Another source is situated so close to the town that the quality of the water is affected somewhat by the population on the territory from which the wells derive their supply, but the water continues to be clear and colorless and safe for drinking. If the towns of Hingham and Hull should join the Metropolitan Water District it might be more economical and satisfactory for the town of Cohasset at some future time to obtain its water supply from the same source. At the present time the sources of water supply of this town are adequate to meet all probable requirements for a long time in the future.

Water Supply of the Town of Scituate.

The population of Scituate in 1920 was 2,534. The town is similar to Cohasset, the permanent population having increased but little for many years, though the summer population is large. The water supply is furnished by the Scituate Water Company from both ground and surface sources, the latter being derived from a very sparsely settled watershed. The surface water is satisfactory except for its color and is filtered before delivery to consumers. The town is adjacent to Cohasset, and if metropolitan water should become available to Hingham and Hull a supply from the Metropolitan Water District might be found more economical and desirable for Scituate, also, than the continued use of present sources. The present sources of supply can be developed to furnish enough water for the needs of the town for a long time in the future unless it should grow more rapidly than in the past.

Water Supply of the Town of Marblehead.

The population of Marblehead, according to the census of 1920, was 7,324. The population of the town has changed but little for many years. In 1920 the total quantity of water used was 635,000 gallons per day, or 87 gallons per person, and 47 per cent of the services were metered. About 37 per cent of the services were metered in 1910, when the consumption of water was 79 gallons per head, and the total quantity used was 577,000 gallons per day. The increase in the total consumption of water since that time has amounted to 58,000 gallons per day, or about 10 per cent. While the town has grown but little in many years, it has a large summer population, and the quantity of water used in the summer season is much greater than in other seasons of the year.

The water supply of Marblehead is taken partly from the ground near Forest River in Salem, and partly from Thompson's Meadow Brook, about one mile west of the ground-water supply. Of the wells located in the valley of Forest River, one is situated close to the river, which was formerly a tidal stream, and is affected by salt water if the quantity drawn exceeds a limited amount. The second well is situated farther east in the bed of a small pond which has been drained and is sunk through about 20 feet of mud into gravel. The water from this well has always contained an excessive amount of iron, and in order to improve its quality a filter was built several years ago. The water of this well, which is the chief reliance of the town, has since been filtered and discharged into the lower well and thence pumped to consumers. The water of Thompson's Meadow Brook is used, after filtration, whenever the flow in that stream is adequate for the purpose, and this water is mixed with that of the well near Forest River. There are wide variations from time to time in the mineral content of the water of the wells, and, in consequence, there is a great variation in the character of the water supplied to consumers. At times the water is clear and colorless, but there are times when it is highly colored and occasionally slightly turbid. The most objectionable feature is probably the hardness which, though occasionally as low as 3.5 parts in 100,000, rises also at times to 10 parts, and averages from 6 to 7 parts in 100,000.

In view of the fact that the town grows but little, it is probable that the present sources of supply can be used indefinitely in the future. Considering the very poor quality of the water in many respects, it is not unlikely that the town will eventually desire to secure a water supply of better quality, either from Lynn or Salem, or from the Metropolitan Water District, since it lies adjacent to the town of Swampscott which is supplied from the district works.

Adequacy of Present Sources to meet the Requirements not only of the Metropolitan Water District but also of Adjacent or Near-by Municipalities.

An investigation of the water supplies of the various municipalities which are not members of the Metropolitan Water District, but are either within the 10-mile limit or adjacent to the municipalities included therein, shows that in many cases the consumption of water has already reached or has closely approached the safe yield of existing sources of water supply. In other cases, while the capacity of the sources is likely to be adequate for ten to fifteen years or more, the water is deteriorating in quality and cannot be used much longer without purification. The delay of many of these municipalities in making provision for adequate enlargement or improvement of their water supplies is probably largely due to conditions brought about by the war, but it is doubtful whether provision for additional water supply would have been so long delayed, in the case of some of these municipalities, at least, were it not for the fact that an additional supply can readily be obtained from the Metropolitan Water District should an emergency arise. Thus the various adjacent municipalities not members of the district are for the present practically secure in the means of obtaining an ample additional water supply at comparatively short notice in case of emergency without incurring any other expense than the cost of any water that they may purchase from the district.

That the Metropolitan Water District can be relied upon to relieve such emergencies has been true, no doubt, up to the present time, but will not continue to be true unless the district enlarges its sources of supply in season to meet adequately its own requirements. If the municipalities in the neighborhood of the district continue to grow as in the past, it is probable that a majority of the population which they contain will have to be supplied with water in part, at least, from the Metropolitan Water District within the next ten years.

Of these cities and towns it is probable that Brookline, Cambridge, Wakefield and Woburn will find it necessary to take water from the district within the next few years, and in all likelihood the towns of Braintree, Weymouth, Canton, Needham, Wellesley and perhaps others also will find it to their advantage to obtain their supplies, in part at least, from the Metropolitan Water District at no distant time. The city of Waltham also can probably secure a part of its supply from the district at less expense than would be necessary for the purification of the water of the lower well which is affected by an excess of iron.

Outside the 10-mile limit, but adjacent to the municipalities included therein, are several places which are likely to seek their supplies from the district, Norwood and Reading especially at an early date, and others at a more remote time.

Changes will occur, of course, which cannot now be foreseen, and municipalities which appear to be capable of supplying themselves from their own sources for many years may find these sources inadequate or unsatisfactory, while the supplies of others may be continued in use for a longer time than is now anticipated. Much will depend upon the prosperity of the Metropolitan District and its growth in population and industry. If, instead of the large number of separate and independent municipalities which are now collected in Boston and its neighborhood, a federation of some sort should be adopted whereby the Metropolitan District would be recorded in census records as a single community, it is probable that there would be a marked acceleration in its growth, as was the case in New York, Chicago, and other cities when similar groups of municipalities were united. The merging of the cities and towns need not be complete and might be only for certain general purposes, but, judging from experience in other cases, if recorded for any purpose as one community, an acceleration in growth would follow and local sources would be depleted at an earlier time. But assuming, as in the estimates presented, that the rate of growth in population will diminish in the future as compared with the past, the situation of the Metropolitan Water District and of the neighboring municipalities with regard to water supply is such that in all probability it will prove to be to the best interests of all concerned that the local supplies shall, so far as practicable, be continued in use, for the present at least, even though a part of the supply in some cases would be taken from the metropolitan works.

The quantity of water which may be required from the metropolitan water works to supplement the local sources will depend upon the extent to which the latter can be developed, upon the length of time that the quality of the water remains satisfactory, and upon the extent to which it is found practicable to filter inferior waters and continue to use them. Making allowance for the full practicable development of present sources, and the continued use of those local sources which are likely to furnish water of satisfactory quality, the following table has been prepared showing the probable requirements of the Metropolitan Water District and of the various adjacent or near-by cities and towns which are likely to need water therefrom within the next ten years (*i.e.*, about 1930), and the probable deficiency in the quantity of water required if no new sources are provided: —

	Million Gallons per Day.			
	1920.	1925.	1930.	1935.
Safe yield of sources of Metropolitan Water District plus Newton.	158.0	158.0	158.0	157.0
Safe yield of sources of near-by cities and towns, which can probably be retained in use.	22.8	22.8	22.8	22.8
Total	180.8	180.8	180.8	179.8
Requirements of Metropolitan Water District and Newton	131.0	145.0	168.5	193.1
Requirements of near-by cities and towns	24.6	28.3	32.3	36.3
Total	155.6	173.3	200.8	229.4
Excess of safe yield over requirements of district alone	27.0	13.0	-	-
Deficiency	-	-	10.5	36.1
Excess of safe yield over requirements, including near-by cities and towns.	25.2	7.5	-	-
Deficiency	-	-	20.0	49.6
Safe yield of present sources which can be retained in use, with Worcester added.	200.1	200.1	200.1	199.1
Total requirements, with Worcester added	172.1	192.5	222.9	254.6
Excess of safe yield over requirements, with Worcester added.	28.0	7.6	-	-
Deficiency	-	-	22.8	55.5

It will be seen from the foregoing table that, while the consumption of water in the Metropolitan Water District is likely to reach the safe yield of the present sources of water supply within about six or eight years at the probable rate of increase in the population and consumption of water, that limit may be reached at an earlier time if water should be supplied to a number of the adjacent municipalities which are likely within a few years to join the district or take water therefrom. This deficiency for the Metropolitan District alone may amount by 1930 to about 10,000,000 gallons per day, while with the addition of the municipalities which are likely to require an additional supply from the district before that time the deficiency in that year may reach 20,000,000 gallons per day. The requirements of the district alone, as at present constituted, are likely to exceed by from 30,000,000 to 35,000,000 gallons the yield of present sources by 1935, and by over 80,000,000 gallons ten years later, and if other municipalities should be added, as will inevitably be the case, these amounts may be exceeded.

PART III. NEW SOURCES FOR METROPOLITAN DISTRICT.

Reconsideration of Sources rejected in 1895.

The investigations of the State Board of Health with reference to a metropolitan water supply in the years 1893–95 included consideration of all the sources which at that time could be regarded as available for the water supply of a proposed Metropolitan District, and included not only the sources situated within the limits of the State of Massachusetts but also Lake Winnipesaukee in New Hampshire and Sebago Lake in Maine. In its report to the Legislature in 1895 the Board presented a summary of the results of its investigations of the various sources, together with its recommendations and plans for a water supply for the Metropolitan District designed not only to meet the requirements of the years immediately following, but capable, also, of development to supply a much greater population as need might arise.

In the quarter of a century or more that has elapsed since the previous investigations were made, many changes have occurred in the uses of the rivers and other waters of the State, and of New England generally, which affect their availability as sources of water supply. The population has grown rapidly in the cities and larger towns and has diminished in areas devoted largely to agriculture, and there has been a great increase in manufacturing industry, including those industries which use large quantities of water in manufacturing processes. The demand for water from public water supply systems for manufacturing and mechanical uses has grown, and the use of water for domestic purposes has also increased, as the multiplication of water fixtures clearly indicates. The quantity of water drawn from public supplies throughout the metropolitan area has nearly doubled, notwithstanding the general introduction of meters, and the rate of increase in the use of water promises to become more rapid than in the past. In consequence, the capacity of many possible sources of water supply which seemed large when compared with the requirements of an earlier time bear a much smaller ratio to the requirements of the present day. There has been a shortage of fuel and an increase in its cost, resulting in the higher development of water power facilities, and, in consequence, in an increase in their value, with a corresponding increase in the cost of damages where water is diverted from streams used for water power. At the same time, the growth of population and industry has increased the quantities of sewage and industrial wastes requiring disposal, and, while works for treating such wastes are common as compared with conditions at the time of the earlier investigation, it still remains a fact that much of the liquid waste from human life and industry in Massachusetts finds its way directly or ultimately into the rivers or other inland waters, with more or less effective treatment in some cases, but commonly with none at all. Under these conditions the diversion of water from a given watershed may affect in a much more marked degree than was the case twenty-five years or more ago the conditions in the valley of the river below. How far such considerations make it desirable to modify the plans presented to the Legislature in 1895 will be indicated in considering the available sources of supply.

The report of the State Board of Health for 1895 includes a list of the sources of water supply then considered, and states that after a thorough review of all of the sources which had been suggested or which the Board could discover, it had selected three which seemed worthy of critical examination, — Lake Winnipesaukee in New Hampshire, the Merrimack River above Lowell, and the Nashua River above Clinton.

Investigations for a water supply for the city of Boston and the municipalities about it have been made from time to time in the last one hundred years. Few of the sources considered in earlier years are worthy of note at the present time, but those mentioned in the investigations of 1893–95 and rejected at that time have been given such further consideration as has seemed necessary under present conditions.

The more important sources to be considered in this part of the report are (1) the Charles River, (2) the Shawsheen River,

(3) the Ipswich River, (4) Assawompsett and other ponds in Lakeville, (5) Sebago Lake in Maine, (6) Lake Winnipesaukee in New Hampshire, and (7) the Merrimack River above Lowell.

The Charles River.

The drainage area of the Charles River at the Boston Manufacturing Company's dam in Waltham, about a mile below the lower well of the Waltham water works, is about 248 square miles, but the rights granted to the proprietors of mills on Mother Brook in Dedham in 1798, to divert one-third of the flow of the river at that point via Mother Brook to the Neponset River, are such that practically all the flow from 66.2 square miles is diverted, and the effective watershed at the before-mentioned point in Waltham is really only about 182 square miles. Until the metropolitan water supply was established Watertown and Belmont obtained water from collecting works alongside the Charles River about a quarter of a mile below the Waltham line, but the water became poor in quality and inadequate in quantity, and the works were abandoned in 1898, when these towns joined the Metropolitan Water District.

At the present time 17 cities and towns obtain their water supplies from the Charles River watershed. The population of these municipalities and the quantity of water used in each in 1895 and 1920, so far as information is available, are shown in the following table: —

Supply introduced.	Municipality.	Population supplied.		Consumption in Gallons per Day.	
		1895.	1920.	1895.	1920.
1873	Waltham	20,876	30,915	1,222,000	1,960,000
1856	Cambridge	81,643	109,694	6,074,000	11,435,000
1874	Lincoln	1,111	1,042	144,500[1]	221,000
1896	Weston	–	2,282	–	159,000
1884	Wellesley	4,229	6,224	175,000	536,000
1876	Newton	27,590	46,054	1,801,000	3,687,000
1890	Needham	3,511	7,012	139,000	450,000
1875	Brookline	16,164	37,748	1,318,000	3,451,000
1881	Dedham	7,211	10,792	419,000	799,000
1891	Holliston	2,718	2,707	79,000	119,000
1891	Millis	1,006	1,485	33,200[1]	61,000
1889	Medfield	1,872	1,900[2]	56,000[1]	76,000[1]
1911	Medway	2,913	2,956	90,300[1]	122,000
1881	Milford and Hopedale	10,336	16,248	527,000	987,000
1884	Franklin	5,136	6,497	201,000	513,000
1908	Wrentham	–	2,808	–	89,000
	Totals	186,316	286,364	12,279,000	24,665,000

[1] Estimated. [2] Omitting asylum population.

It appears from the above table that, while the population of the municipalities supplied with water from this watershed has increased 54 per cent in the last twenty-five years, the quantity of water consumed has increased 101 per cent. Moreover, of the 24,665,000 gallons of water consumed daily in the municipalities supplied with water from the Charles River valley in 1920, about 22,000,000 gallons were delivered to municipalities in which the sewers have outlets outside the Charles River drainage area, and the quantity of water diverted from the watershed is further augmented by leakage into the sewers. A new main branch of the metropolitan sewerage system extending through the valley from West Roxbury to Wellesley, just completed, will divert a large additional quantity of water from this drainage area.

The flow of the river in the lower part of its course, especially below Newton Upper Falls, has been very low in past dry seasons, and in the period 1910–11 such measurements as are available indicate that the quantity of water actually diminished during the drier part of the year as the river flowed toward its outlet after passing Newton Upper Falls. The diversion of water from the Charles River watershed has been greatly increased since the last dry period, and if a reservoir should now be constructed in this watershed with a view to using the water of the upper part of the watershed for water supply purposes, a large part of the water would have to be allowed to flow past the dam in order to maintain satisfactory conditions in the river below, to furnish water for industrial uses, and especially to prevent diminishing the yield of the sources of water supply in the valley of the river below the reservoir.

Below Watertown is the Charles River Basin formed by the building of a dam at the site of the old Craigie bridge in 1910. As the water in this part of the river is kept at a constant level, and as it is desirable to maintain a fresh water basin in this populous district near the mouth of the river, it would seem that the amount of water already abstracted from the drainage area of the river above has about reached the point where little more, if any, can be diverted in periods of minimum flow without danger of causing objectionable conditions.

The Charles River was carefully examined in 1874 with a view to its use as a source of water supply for the city of Boston. In the course of that investigation sites were found for two large storage reservoirs and surveys made to determine the probable area and capacity of each and the amount of water that might be obtained therefrom. One of these reservoir sites was located above Newton Upper Falls where, by the construction of a dam not far from the present Newton water works pumping station, a reservoir could be formed which would flow a great area consisting largely of meadows and swamps extending along the river in Newton, Needham, West Roxbury, Dedham, and beyond, an area which now contains the water supplies of Brookline, Newton and Dedham, and is surrounded by a rapidly growing population. The construction of such a reservoir would obviously be impracticable at the present time.

The other and more favorable site is located farther up the river where a reservoir could be formed by a dam near South Natick which would flood an area of 4,000 or 5,000 acres, extending many miles upstream to the neighborhood of Medway. About 50 per cent of the area which would be covered with water by such a reservoir would be swamp and meadowland, including the Medfield meadows, so called, and unless this area were properly prepared for the purpose the reservoir would not only furnish water of very poor quality, but would no doubt be a serious nuisance to the villages and dwelling houses along its banks at times when the bottom was exposed by drawing down the water, and possibly, also, from large aquatic growths, which have become very objectionable in shallow ponds and reservoirs with muddy bottoms in populous districts. The river above this proposed reservoir receives much pollution from the towns on its watershed, which would render the condition of the reservoir more objectionable than might otherwise be the case. The area of the watershed tributary to a reservoir in this location would be about 156.3 square miles, and the area of the basin itself, according to available surveys, about 6.1 square miles if the water level were raised 15 feet, and 7.94 square miles if the water were raised 21 feet. The reservoir would hold about 9,000,000,000 gallons with an average depth of about 9 feet, or 18,000,-

000,000 gallons at a 12-foot depth, and might furnish a safe yield of from 63,000,000 to 93,000,000 gallons per day, depending upon the height of the dam.

All the conditions point to the conclusion that the amount of water which would be available to the Metropolitan Water District from a storage reservoir above South Natick after deducting all necessary allowances, including losses from evaporation, would be much less than the estimated safe yield. The cost of the reservoir, together with the cost of properly purifying the water and conveying it to the district, would unquestionably be excessive in view of the quantity likely to be obtained.

The proposition to develop this river as a water supply for the city of Boston was rejected for excellent reasons nearly fifty years ago, and these reasons have more force at the present time. The plan appears so obviously impracticable that a study of it in detail has seemed an unnecessary expense.

The Shawsheen River.

The Shawsheen River was examined with reference to its use as a source of water supply for the city of Boston in 1874 and again in 1886–87, when surveys were made for possible reservoir sites in this valley. The results of these investigations indicated that this source could possibly be developed to yield about 20,000,000 gallons per day, but great objection was made to the taking of water from this river for water supply purposes, and the scheme was finally rejected by the Legislature in 1886. The water is highly colored, of poor quality for domestic use, and the reservoir sites, which are largely swamps, would require extensive preparation if they were to be used for water supply purposes at the present time in a region which contains a considerable and growing population. The quantity of water obtainable from this source at its highest practicable development would not add more than about 12 per cent to the safe yield of the present sources of the Metropolitan Water District. In the case of this stream, as in that of the Charles River, a large quantity of water would have to be discharged below the lowest dam to maintain satisfactory conditions in the river, and the cost of the development of a supply of water of satisfactory quality, considering the small quantity of water obtainable, would be excessive.

The Ipswich River.

The Ipswich River and its tributaries are now used as sources of water supply by the cities of Lynn, Peabody, Salem and Beverly, and by the towns of Danvers, Saugus, Reading and Middleton. If used for the Metropolitan Water District in addition to the municipalities which now take water from it, or are likely to require water from this watershed in the future, there might be a small quantity of water remaining for the use of the Metropolitan Water District for a short time, but the large and rapidly growing municipalities in the part of the State in which it lies require that this watershed should be developed for their uses alone, and this source should be kept for that purpose.

Assawompsett and Other Ponds in Lakeville.

These ponds were considered as possible sources of water supply for the district in 1895, but they are already in use and are so obviously required for the population of south-eastern Massachusetts that they cannot now be considered as available for the use of the Metropolitan Water District.

Sebago Lake.

Sebago Lake in Maine is more than 100 miles from the State House in Boston, and lies at an elevation of 251, or about 10 feet lower than that of the Sudbury Reservoir. The cost of works for bringing this water to Boston would be much greater than for bringing water from Lake Winnipesaukee, and the latter source would have far greater advantages for the purpose if it should be deemed necessary to go outside of the State in order to obtain an additional water supply for the Metropolitan Water District.

Lake Winnipesaukee.

A thorough investigation as to the possible use of Lake Winnipesaukee for the water supply of the Metropolitan Water District was made by the State Board of Health in 1893–95, but this source was not recommended owing to its location outside the State and the excessive cost of obtaining water therefrom.

The difficulties in the way of obtaining a water supply for the Metropolitan District from Lake Winnipesaukee without doubt would be even greater to-day. The taking of the storage of that lake for water supply purposes would diminish the flow of the Merrimack River and diminish materially the water power of the State of New Hampshire as well as that of Massachusetts. That such a proposition would be assented to, together with authority to enforce proper police protection of the lake by the State of New Hampshire, is too improbable to warrant further consideration of that source of water supply at the present time.

The Merrimack River.

Investigations were also made in 1895 with reference to the use of the water of the Merrimack River above Lowell for the water supply of the then proposed Metropolitan Water District, and the results are presented in considerable detail in the report of that year. The Merrimack River above Lowell drains a net area of about 3,979 square miles, and above Lawrence about 4,452 square miles, and if diverted at either place would furnish an almost inexhaustible water supply for the Metropolitan Water District. The larger of the municipalities in that part of the drainage area which lies above the city of Lowell, with their population in United States census years from 1880 to 1920, are shown in the following table: —

Population, 1880–1920.

	1880.	1890.	1900.	1910.	1920.
New Hampshire:					
Franklin	3,265	4,085	5,846	6,132	6,318
Laconia	3,790	6,143	8,042	10,183	10,897
Concord	13,843	17,004	19,632	21,497	22,167
Manchester	32,630	44,126	56,987	70,063	78,384
Nashua	13,397	19,311	23,898	26,005	28,379
Totals	66,925	90,669	114,405	133,880	146,145
Massachusetts:					
Leominster	5,772	7,269	12,392	17,580	19,744
Fitchburg	12,429	22,037	31,531	37,826	41,029
Totals	18,201	29,306	43,923	55,406	60,773
Grand totals	85,126	119,975	158,328	189,286	206,918

Raw sewage is discharged directly into the river or its tributaries without any treatment whatsoever from most of the municipalities along its banks except Fitchburg, where the greater part of the sewage is treated at purification works before its discharge into one of the tributaries of the Merrimack. The river and its tributary streams are also polluted by manufacturing wastes from numerous factories and mills in the towns and villages in this populous manufacturing valley. Water taken from the Merrimack River above Lawrence is used for the water supply of that city at the present time after filtration and sterilization, and there is no doubt that the water of this river could be used for the water supply of the Metropolitan District if necessary, provided it were properly filtered. The most favorable point at which to take water for the Metropolitan District would probably be above the dam at Lowell, where the pollution of the stream is less than would be the case if taken below that city.

Plans of works for utilizing water from this source for the supply of the Metropolitan Water District made in 1895 provided for the construction of 32 acres of filters in the beginning, and for gradually increasing the area from time to time as might be required. The total first cost of the works, exclusive of damages for diversion of water, was estimated at that time at $14,839,000, and the cost of operating the filters and pumping stations, together with damages for the diversion of water, capitalized at 5 per cent, for 65,000,000 gallons per day, was estimated at $2,624,000, making the total estimated cost of these works at that time $17,463,000, an amount about 8 per cent less than the estimated cost of the construction of the works for taking water from the Nashua River finally adopted by the Legislature in 1895.

At the time of the earlier investigation it was proposed to pump the water from the Merrimack River to filters to be located at Wilmington, and to pump the filtered water thence to the distributing system of the Metropolitan Water District. A modification of this plan would no doubt be found desirable at the present time, since objection might be made to the disposal of polluted wash water within the watershed of the Ipswich River, which is now used as a source of water supply by cities and towns below the location of the proposed filters. The filters might be located in the neighborhood of the Merrimack River, but this might involve a considerable additional cost as compared with the Wilmington site, unless suitable materials for filter construction are available in the neighborhood of the Merrimack, as is the case at Wilmington.

The use of filtered water of a character such as that obtainable from the Merrimack River might make necessary the construction of covered reservoirs in connection with the distributing system. Otherwise organisms which cause objectionable tastes and odors might grow in the filtered water when exposed to light, as in the case of the open distributing reservoir at Lawrence, though complaint from this cause has occurred on only a few occasions. Both the first cost and the maintenance of works for filtering the water of the Merrimack River would be greater to-day than in 1895 on account of the higher cost of fuel and labor and of the materials and machinery required for the construction of pumping stations, power units, filters, and their appurtenances. But a most important item of cost of a water supply from the Merrimack River which would be much greater to-day than in 1895 would be the damage to the mill powers at Lowell and Lawrence. It would be possible for a few years, when the quantity of water required would be comparatively small, to draw water from the river only in the winter and spring when the flow is in excess of that used for power, and to supply the district during the remainder of the year from the present sources. But it would soon be necessary at times to divert an additional quantity, and a draft would be made upon that part of the flow of the stream which would otherwise be used for power. As the amount of water required would constantly increase, the available water power at Lowell and Lawrence would be gradually diminished. This loss of power might be prevented by constructing storage reservoirs on the river above the point of diversion, and using them by drawing their waters into the river and subsequently withdrawing them near Lowell or Lawrence. But there are no practicable sites for suitable reservoirs of adequate size in Massachusetts, and the construction of such reservoirs by the Metropolitan Water District within the limits of the State of New Hampshire would be impracticable. The use of the Merrimack River would sooner or later reduce materially the quantity of water available for power in this important stream. A further important item to be considered in connection with the diversion of water from the Merrimack River, which was less evident at the time of the earlier investigation, is the probable necessity of the construction of works for maintaining proper sanitary conditions in the valley of the Merrimack River below the point of diversion. Already in dry periods there has been complaint of the insanitary condition of the Merrimack River at points below Lawrence, and with the growth of population and industry in the Merrimack River valley it is certain that the diversion of some, at least, of the pollution of this stream, or the treatment of a part of the sewage and waste which are now discharged into the river, will become necessary at no distant time. If the Metropolitan District should now divert a considerable percentage of the dry weather flow of the river above Lowell, the objectionable conditions in the river below would become more acute, and a part at least of the cost of improving the sanitary conditions in the river below would doubtless be considered chargeable to the Metropolitan Water District.

The taking of water from the Merrimack River for the water supply of the Metropolitan Water District would not only reduce materially the water power of the State available for industrial uses, but would also involve the installation of power plants for pumping the water required by the district, and the use of an ever-increasing quantity of fuel for the purpose, or the purchase of power which would otherwise be available for other uses.

But most important of all, the taking of water from the Merrimack River would supply the Metropolitan Water District from a polluted source which is gradually and surely growing worse. The objections to this scheme in 1895 were summed up by the chief engineer of the Board at that time, as follows: —

Of these two plans, I have no hesitation in recommending the one for taking water from the Nashua River, mainly because I believe that the small advantage which the Merrimack River plan has in regard to cost does not outweigh the disadvantage of taking a water which requires purification to make it suitable for drinking. Even if it were admitted that sand filtration with scientifically constructed filters and intelligent management will entirely remove disease germs from water, there is still the chance in the administration of a work of this kind that the preparation may be unscientific and the management unintelligent, which may cause the water to be either imperfectly purified by filtration, or, by accident, carelessness or the necessity of maintaining the supply, sent to the Metropolitan District without any filtration whatever. There is another objection to the Merrimack scheme which I regard as of importance, — that there is a greater danger that the supply may be interrupted through some accident at the pumping stations or filter beds, or by a temporary failure of the supply of coal or of skilled labor required to operate the works. . . .

The objections to the use of this river as a source of water supply are far more serious in all respects than was the case twenty-five years ago. The population on the watershed above is increasing, and the water is becoming more polluted from year to year, entailing greater care and cost in the operation of filters in order to insure its proper purification, and involving greater danger of interruption in the efficient operation of the works.

It is unreasonable to incur the possible danger of injury to the public health which the use of this supply would involve, from an unexpected inadequacy of the filters or inefficiency in their operation, so long as it is practicable to obtain an ample water supply for the district from unpolluted sources.

Other Watersheds.

The Upper Mystic Lake, formerly used for the water supply of a part of the city of Boston and adjacent municipalities, was abandoned when the metropolitan water supply was introduced. The water is unfit for domestic use.

The Neponset River is too badly polluted for use as a water supply, though some of its tributaries near their headwaters are capable of furnishing small supplies of water for local uses.

The Taunton River is too badly polluted for use as a source of water supply, and the same is true of a number of its tributaries, though in a few cases the tributaries are not seriously polluted at the present time. It is not advisable, however, that water be diverted from the Taunton River or other sources in this region, since the available supplies are limited and should be retained for the use of the municipalities in that part of the State.

The Blackstone River is too badly polluted for use as a source of water supply.

The Concord River flows through extensive meadows in a wide flat valley for nearly its entire length from the junction of the Assabet and Sudbury rivers in Concord to North Billerica not far from its mouth. There is no practicable site for a storage reservoir at any point on this stream at which a considerable supply of water could be developed.

The North Branch of the Nashua River, like the Blackstone, is too badly polluted for use as a source of water supply, and the same is true of the main stream of the Nashua River below the junction of the North and South branches. The only tributary of considerable size, the Squannacook River, would furnish comparatively little water in proportion to the cost of its development for use as a source of additional water supply for the Metropolitan Water District.

Investigation of Sources recommended in 1895.

The plans for a metropolitan water supply submitted to the Legislature in 1895 by the State Board of Health provided for the immediate taking of the South Branch of the Nashua River for use in connection with the Sudbury and Cochituate supplies of the city of Boston which were to be taken over for the purpose. But the Board's plan provided not only for the immediate needs of the proposed district, but for future extension of the works as the needs of the district might require, first to the Assabet, Ware and Swift rivers, and subsequently, as further needs might appear, to the Deerfield and Westfield rivers which drain large areas in the Green Mountains and the easterly slopes of the Berkshire Hills west of the Connecticut River.

This scheme was promptly adopted by the Legislature of 1895, and the immediate construction of the Wachusett Reservoir was undertaken, together with the completion of the Sudbury Reservoir (begun by the city of Boston) and the construction of the necessary aqueducts and other appurtenances of the present metropolitan water supply system which has so admirably served the requirements of the Metropolitan Water District for nearly a quarter of a century.

When the present investigation was begun under the direction of the Legislature of 1919, the plans presented by the State Board of Health to the Legislature of 1895 were taken up immediately for further consideration. Included among the plans prepared for the 1895 report were plans for additional storage reservoirs, one to be located in the valley of the Ware River near Coldbrook in the towns of Barre and Oakham, and the other in the valley of the Swift River above West Ware, together with an outline of possible diversions of tributaries of the Assabet River into the then proposed Wachusett Aqueduct.

The surveys made in 1895 for possible reservoirs in the Ware and Swift river valleys, while somewhat general, were considered sufficiently accurate for use as a basis for additional surveys and plans for the present investigation.

In the present investigation the possible locations for dams and reservoirs have been surveyed and reconnoitered with the advice of geologists of experience in such investigations, and the favorable sites have been examined by the aid of borings to determine the depth to rock and its character, as well as that of the overlying material, so that at least in the case of the sites chosen for an estimate of cost for this preliminary report enough data have been secured to establish a provisional profile of ledge rock at the most critical points in the cross sections of the valleys. Cultural surveys have also been made of the areas which might be flowed for reservoir purposes to determine the number of buildings, the character of the soil, and the extent of the use of land for various purposes. Aqueduct lines have been reconnoitered and surveys have been made of aqueduct locations where necessary and practicable with the funds available. At the same time, information has been collected as to the rainfall in these watersheds, the flow of the rivers and the probable yield of reservoirs which might be built within these drainage areas, and the probable effect of the diversion of water therefrom upon the industrial and other uses of the rivers below the proposed points of diversion of their waters.

The Assabet River.

In the report of 1895, relative to a metropolitan water supply, certain tributaries of the Assabet River are mentioned as the first probable extension of the metropolitan water supply system when an additional supply should become necessary.

The Assabet River watershed lies between that of the Sudbury on the east and the Nashua on the west, and drains a total area of 176.8 square miles above its junction with the Sudbury River at Concord. Its drainage area at various points is given in the following table: —

	Square Miles.
Assabet below Westborough sewage filtration area	8.0
Assabet below Hudson	73.3
Assabet below Maynard	115.6
Assabet at mouth	176.8

Investigations made in connection with the report of 1895 upon a metropolitan water supply indicated that the waters of several streams in the upper part of the Assabet River watershed, through which the Wachusett Aqueduct passes in its course to the Sudbury Reservoir, could be utilized for supplementing the metropolitan water supply by diverting them into the aqueduct through some six separate connections. In the report of the chief engineer it is stated that a total drainage area of about 34.4 square miles could in this way be diverted into the aqueduct and thence into the Sudbury Reservoir, and the available yield of the metropolitan sources thus increased about 28,000,000 gallons per day at a comparatively small cost. This scheme has been carefully reconsidered to determine the amount of water that it is practicable to obtain from this source at the present time, and whether it is an advantageous one to use as an additional water supply for the Metropolitan Water District. The streams which might be diverted from this watershed into the Wachusett Aqueduct, together with the watershed of each, are shown in the following table: —

Subdivisions of Upper Assabet River Watershed.

Watershed.	Area (Square Miles).	
North branch of brook above West Berlin	2.85	
South branch of brook above West Berlin	4.52	
Brook northeast of Barnes Hill	.75	
Brook northeast of Mt. Pisgah	.52	
Brook south of Sulphur Hill	.77	
Howard Brook	1.61	
Cold Harbor Brook	6.51[1]	
Hop Brook	4.37	
Total area which could be made tributary to the Wachusett Aqueduct		21.90
Bummet Brook	1.47	
Upper Assabet River	7.52	
Total area from which water could be conveyed by new aqueduct to Sudbury Reservoir.		8.99
Total area possible of diversion		30.89

[1] The water supply of the town of Northborough is drawn from 2.42 square miles in this area.

There has been no material change in the character of the water of most of these tributaries since 1895. Their watersheds are for the most part sparsely populated, and water of good quality for water supply purposes can be obtained from them at the present time. One of these streams, however, is used as a source of water supply by the town of Northborough. The watershed of another, which drains an area along the Boston & Albany Railroad above Westborough, has become much more populous than was the case twenty-five years ago, and furthermore, the sewage disposal works of the town of Westborough are located in the valley just below a suitable point of taking. If the flow of this tributary were to be diverted as proposed, little water would be left in the stream during the drier part of the year to dilute the effluent from those works. There has been much litigation already over the condition of the river below this sewage disposal works, and under the circumstances the diversion of water from this tributary at the present time seems inadvisable.

Omitting the latter area and another small one which would necessarily be grouped with it, but without allowing for the diversion of water from one of these areas by the town of Northborough, the total net watershed remaining is 21.9 square miles. Even if all of the water practicable should be diverted from this area for the use of the Metropolitan Water District the additional safe yield thereby obtained would not exceed 17,000,000 gallons per day. It is inadvisable, however, to divert the water of these streams at the present time because of the conditions in the valley of the Assabet River below the points of diversion.

The Assabet River valley below the areas drained by these streams contains several large towns in which are located important factories and mills some of which use large quantities of water in their processes. One of these establishments, the woolen mills at Maynard, uses at times the entire dry weather flow of the river for such purposes. Furthermore, in addition to the effluent of the sewage disposal works of the town of Westborough, that of the town of Hudson is also discharged into the stream, and similar disposal is made of the effluent from a sewage disposal works in the town of Maynard which enters a tributary below that town. The river has been the source of much complaint in past years on account of pollution by sewage and manufacturing waste, and considerable litigation has resulted therefrom. Its condition finally became so objectionable that the Legislature passed a stringent law designed to prevent further objectionable pollution. The conditions now existing in the valley are such that if the flow of the river were diminished by the diversion of all the water from the areas indicated during the drier part of the year, the condition of the stream would no doubt become more objectionable.

Under the circumstances it is difficult to estimate the probable damage and expense which might result from the taking of the entire flow of these streams in addition to the cost of damage to water power alone. That the expense would be large there would seem to be no question. But it is not at all probable that so complete a taking would or should be authorized at the present time. The Legislature in the past has limited the taking of water from rivers for water supply uses by requiring that a part of the water shall be allowed to flow past the point of taking, and these limitations have apparently been increasing. In authorizing the taking of water from the Sudbury River by the city of Boston in 1872 the law required that an amount of water equivalent to 20,000 gallons per square mile per day should be allowed to run in the river below the lowest dam, and in the case of the taking of the South Branch of the Nashua River in 1895, provision was made for a maximum discharge of about 29,000 gallons per square mile per day. In the case of the takings of water from the Ipswich River by the various municipalities authorized to take water from that stream, beginning in 1902 and especially later in 1913, reservations were made which provided that no water at all should be diverted from that river at any time between the months of June and November, inclusive, and that water should be taken in the remaining months only at times when the flow exceeds a certain specified quantity amounting in the different cases approximately to from 200,000 to 230,000 gallons per square mile per day, or, in the latter case, to about 0.35 of a cubic foot per second per square mile.

The conditions in the valley of the Assabet River below the proposed points of taking are quite different from those in the valley of the Ipswich River below the authorized points of taking on that stream. While the watershed of the Assabet River contains large towns and important industries, the watershed of the Ipswich River, on the other hand, contains few manufacturing establishments of any kind, and, excepting at the mouth of the stream where it enters the sea, no considerable town. Moreover, the quantity of sewage or industrial waste which finds its way into this river above Ipswich is comparatively insignificant. While sewage and manufacturing waste can be so treated that the resulting effluents may not create offence when discharged into a stream, they will still contain more or less matter which, unless well diluted, may so affect the character of the water that, though perhaps inoffensive, it may be objectionable for certain uses below.

The advisability, as a general policy, of limiting the amount of water that may be diverted from the rivers of the State so as to prevent serious diminution of their flow, especially at times when the flow is small, will hardly be questioned at the present time.

With conditions as they now are, if water is to be taken from streams in the Assabet watershed as proposed, the taking should be a limited one.

If authority were obtained to take all of the flow of these streams in excess of .35 of a cubic foot per second per square mile of watershed, or about 225,000 gallons per square mile per day, without other limit as to quantity or time of diversion, the safe yield obtainable from the use of these streams in the Assabet River watershed would be about 11,000,000 gallons per day. If the taking should be limited to flows in excess of 1.2 cubic feet per second per square mile, or about 775,000 gallons per square mile per day, the safe yield obtainable from these tributaries of the Assabet River would be about 7,000,000 gallons per day. The latter limit of taking will be suggested later in the case of other rivers where conditions are similar. If a taking of all the flows in excess of .35 of a cubic foot per second per square mile should be allowed, the quantity of water thus obtained would be sufficient for the needs of the district for about three years after the capacity of the present sources had been reached. If the taking is confined to flows in excess of 1.2 cubic feet per second per square mile, the additional quantity of water would meet the requirements of the district for about two years after the safe yield of the present sources had been reached.

Considering the fact that a very much larger supply must be provided within so short a time to meet the needs of the district and of the other municipalities which may be supplied therefrom, there is no probability that any considerable saving in the cost of an additional water supply for the district can be effected by a permanent taking of water from these tributaries of the Assabet River under the conditions existing at the present time. Since, however, most of the streams in this part of the Assabet River watershed can be diverted readily and quickly into the Wachusett Aqueduct by gravity, they could probably be used temporarily in case of an emergency under the provisions of chapter 40, section 40, of the General Laws.

The Upper Ware River.

The watershed of the Ware River lies adjacent to that of the Nashua River on the west, but while the Nashua River flows northeast to join the Merrimack at Nashua, and its waters finally discharge into the Atlantic Ocean at Newburyport, the Ware River flows southwest to the Chicopee, one of the main tributaries of the Connecticut River, and its waters eventually find their way into Long Island Sound.

The practicability of using water from the Ware River to supplement the Nashua River and the metropolitan water supply system was quite thoroughly considered and reported upon by the State Board of Health in 1895. A favorable site for a reservoir was found on the Ware River at Coldbrook in the towns of Barre and Oakham. Such a reservoir would have an area of 1,035 acres and a drainage area of about 100 square miles.

The surveys of this proposed reservoir made in 1895 have been considered suitable for present purposes so far as they go, and these surveys have been supplemented by further studies of railroad and highway locations and of possible sites for a dam. It has not been practicable to make borings to determine the actual subsurface conditions at the proposed location for a dam, nor has such a further study been deemed necessary in connection with this preliminary investigation.

Conditions in 1895 compared with those to-day.

The conditions in the valley of the Ware River above Coldbrook remain practically the same as at the time the previous report was made. The population on the watershed, which was equivalent to about 32 persons per square mile at that time, is probably somewhat less to-day, and no material changes have occurred in other respects which would affect the quality of the water.

There are no large towns or villages in the watershed and no large industries producing wastes likely to pollute the streams, and none are likely to be established there.

Aside from its color, which averaged .56 on the scale of color in 1921, the water is naturally excellent for water supply uses.

The objection due to color is not a serious one under the circumstances, as it is probable that it could be reduced by the drainage of swamps on the watershed, and in any case would probably largely if not wholly disappear in the reservoirs through which the water would pass before reaching consumers in the Metropolitan Water District, even though no reservoir were constructed in the Ware River watershed.

Diversion by Tunnel to Wachusett Reservoir.

In the report of 1895 it was proposed to divert the water from a reservoir at Coldbrook in this watershed into the Wachusett Reservoir by gravity through a comparatively high level tunnel about 9 miles long. It was also indicated that by placing the tunnel at a lower level the tunnel would be about 13½ miles long and could be extended subsequently to the Swift River when a further additional water supply should become necessary. It was estimated that the additional quantity of water obtainable from the Ware River with the proposed reservoir would be 71,000,000 gallons per day.

Undoubtedly the most appropriate plan of increasing the water supply of the Metropolitan Water District at the present time will be to take water from the Ware River above Coldbrook into the Wachusett Reservoir. If the whole flow of the river above Coldbrook were taken as proposed in 1895, the additional supply thus obtained would be sufficient for the district alone for about fifteen years after the consumption of water reaches the safe yield of the present works, which will probably be about 1928 to 1930. But if the municipalities which now seem likely to require water from the metropolitan sources within the next few years are included, the supply obtained in this way would probably not be sufficient to meet all requirements for a much longer period than about twelve years after the consumption of water equals the safe yield of present sources. A further extension would then become necessary, and in that case the most desirable source from which to take a further supply would be the Swift River. In order to take water from the Swift River into the Wachusett Reservoir by gravity it would be necessary to provide a longer tunnel at a lower level than if water were to be taken from the Ware River only, as has already been suggested. A tunnel at the higher level would be shorter and cheaper, but if the tunnel were constructed at the higher level it would be useful for a comparatively short time only, since, when it should become necessary to take an additional supply from the Swift River, it would be essential, in order to obtain a gravity supply, to duplicate later at a lower level that part of the tunnel from the Wachusett Reservoir to the Ware River. Even allowing that the cost of such work might be much less in the future, it would be more economical, in view of the probable growth of the Metropolitan Water District, to construct the tunnel at the lower level in the beginning.

By taking the entire flow of the Ware River so far as possible through a tunnel to Wachusett Reservoir, it would be practicable to obtain a large additional water supply for the Metropolitan Water District, and to postpone for several years the construction of the proposed reservoir at Coldbrook. With a tunnel of the size which it would be desirable to construct, having in view the probable need of future extension, nearly as great an increase in the yield of the sources of the Metropolitan Water District could be obtained without building the reservoir as would be obtained if the proposed reservoir were constructed. But the taking of the entire flow of the river would involve greater damages than when proposed in 1895.

Limitation of Diversion to the Higher Flows.

Along the course of the Ware River, between Coldbrook and the confluence of the Ware River with the Swift and Quaboag rivers at Three Rivers, there are important manufacturing establishments, including woolen and paper mills, which use large quantities of water in manufacturing processes and which also discharge large quantities of manufacturing waste. At Ware, the principal town in the valley, the river is polluted not only by manufacturing wastes, but by the sewage of the town, which is discharged directly into the stream. The diversion of practically the entire flow of water from the Ware River above Coldbrook would reduce greatly the dry weather flow of the river at points below Coldbrook.

It is very difficult to estimate the probable extent of the damages that might result from the taking of the entire flow of the Ware River above Coldbrook in addition to the damage to water power alone. That the damages would be large there would seem to be no question. Such a taking would diminish by half the flow of the river at a point not far above its mouth, and in increasing proportion from point to point up the stream, while in the vicinity of the dam there would be little or no flow at all after the full supply came to be required by the district, except such amounts as might be wasted at times of high freshets, usually in the early spring.

The statements made with reference to the diversion of water from the Assabet River apply to the Ware River as well, and if large costs and damages are to be avoided, injury to the prosperity of the valley prevented, and a satisfactory condition of the river maintained, it will be necessary to limit the amount of water that may be diverted from the river.

As will be shown later, it will be practicable, by building a reservoir on the Swift River, to combine the flow of several rivers including the Ware, and obtain a very large additional supply for the Metropolitan Water District by limiting the diversion of water from any river to the flows in excess of 1.2 cubic feet per second per square mile of watershed. With this limit of diversion the amount of water which could be diverted from the Ware River for use in connection with the Wachusett Reservoir alone would be about 33,000,000 gallons per day in a dry period. Later on, after the completion of the proposed tunnel to the Swift River, the amount of water which could be diverted from the Ware River under the same taking would be increased to 47,000,000 gallons per day, since the extension of the tunnel would make it practicable to store a part of the water in the Swift River Reservoir which would otherwise run to waste so long as only the lower, or Ware–Wachusett, end of the tunnel was built.

By limiting the taking of water from the Ware River watershed to flows in excess of 1.2 cubic feet per second per square mile, the amount obtainable would be less of course than if the entire flow of the stream were taken, or if a lower limit than 1.2 cubic feet per second per square mile were established;

but it would probably make no great difference to the Metropolitan District in the cost of its water supply whether it were authorized to take all of the flow of the Ware River above Coldbrook or were limited to a taking of flows in excess of 1.2 cubic feet per second per square mile. In the former case the damages would be much larger than in the case of taking only the higher flows, but in the latter case it would be necessary to extend the works to the Swift River at a somewhat earlier date, and the difference in cost probably would not be material. On the other hand, the difference in the amount of water diverted would be an important one to the inhabitants of the Ware River valley, since under the higher taking no water would be diverted from the river except at times when the flow exceeded about 775,000 gallons per square mile per day, which is about 80 per cent of the average flow of the stream, while the flow in freshets with their objectionable features would be very greatly reduced.

Under favorable circumstances the construction of the proposed reservoir at Coldbrook might postpone for a few years the time when it would be necessary to construct the Swift River Reservoir and the tunnel thereto, dependent upon the yield of watersheds in the period when its construction would be completed and upon the rate of increase in the consumption of water in the Metropolitan District and in such other municipalities as may be dependent thereon for water at that time. The cost of the construction of the proposed reservoir would probably at least equal the saving in interest that would be effected by postponing the extension of the tunnel to the Swift River, and it might exceed that amount. On the whole, the value of this proposed reservoir after the completion of the works to the Swift River would be slight, and its construction now seems inadvisable.

In conclusion, as already stated, undoubtedly the most appropriate method of increasing the water supply of the Metropolitan Water District, and the first step toward securing an additional supply, is the construction of the aqueduct as far as Coldbrook, which will make possible the diversion of the higher flows of the Ware River above that point into the Wachusett Reservoir.

The Lower Ware River.

The Lower Ware River, mentioned in the report of the State Board of Health of 1895, is that part of the Ware River which lies between Coldbrook and Gilbertville, and which has a watershed of about 50 square miles at a convenient point of diversion above the latter village opposite Mandell Hill. It was proposed in the report of 1895 to utilize this portion of the Ware River watershed in connection with a water supply from the Swift River by diverting the flow or such part of it as could be made available into the proposed aqueduct from the Swift River to the Wachusett Reservoir. Conditions in this part of the Ware River watershed have changed considerably, as already indicated, since the report of 1895 was presented, and the river now receives much polluting matter in this part of its course of such a character as to injure seriously the quality of the water for domestic use. The quantity of these wastes is such that in consequence the expense for works necessary to make it practicable to utilize all the waters of this portion of the Ware River would make the cost excessive for the amount of water obtainable.

Furthermore, recent study of the proposed tunnel line from the Wachusett Reservoir to the Swift River has shown that its length can be lessened materially and much expense saved by adopting a line which is practically straight from the upper end of Wachusett Reservoir to an intake in the Swift River valley at a convenient point opposite Greenwich. This more northerly location of the tunnel will be more economical and will provide for the location of the tunnel and shafts at such points in the Ware River watershed that the flow from at least 19, and probably more, of the 50 square miles of catchment area below Coldbrook can be easily and economically diverted directly into the aqueduct whenever it is desirable to do so.

The Swift River.

The Swift River is one of the principal tributaries of the Chicopee and drains an area of about 213 square miles above its confluence with the Ware at Palmer. Its watershed is approximately midway between the seashore at Boston and the western boundary of the State. The preliminary investigations of the State Board of Health in 1895 indicated that a large reservoir could be created in this valley by the construction of a dam on the main river about 3 miles below the village of Enfield, supplemented by a dike across the valley of Beaver Brook about 3 miles northeast of the dam near a low place in the divide between the Swift and Ware rivers, through which the waters of a reservoir on the Swift River might overflow into the valley of Beaver Brook in the Ware River watershed.

The Swift River is formed by three main branches, two of which — the East and Middle branches — unite at a point in the southwesterly part of the town of Greenwich about 2 miles above the village of Enfield, while a third, known as the West Branch, joins the main river about 1.5 miles below that village. The watershed of the Swift River is characterized by a series of high ridges running generally parallel in a northerly and southerly direction. The middle and upper portion of the valley is occupied by an extensive sandy plain with a number of rugged, mountain-like rocky hills which rise 300 to 500 feet above the valley floor. Through this plain flows the Middle Branch of the river in a southerly direction from its headwaters in a number of ponds 6 or 8 miles south of the Millers River, with the villages of North Dana and Millington on its upper waters. The East Branch, which drains a high and hilly country in the easterly part of the watershed, enters the plain near its southerly end, joining the Middle Branch near the southwesterly corner of the town of Greenwich, which with its two villages occupies this part of the watershed. The main river turns abruptly to the southwest not far from this point and enters the comparatively narrow valley in which the town of Enfield lies. The plain, however, extends nearly due south, rising gradually to the broad, low divide between the Swift and the Ware river watersheds, which makes necessary the construction of a dike in this region if a large reservoir is to be created in the Swift River valley. The main river continues through the valley, in which are located the villages of Smiths and Enfield, to its junction with the West Branch, when it turns to the south and flows through a wider valley to the dam site below.

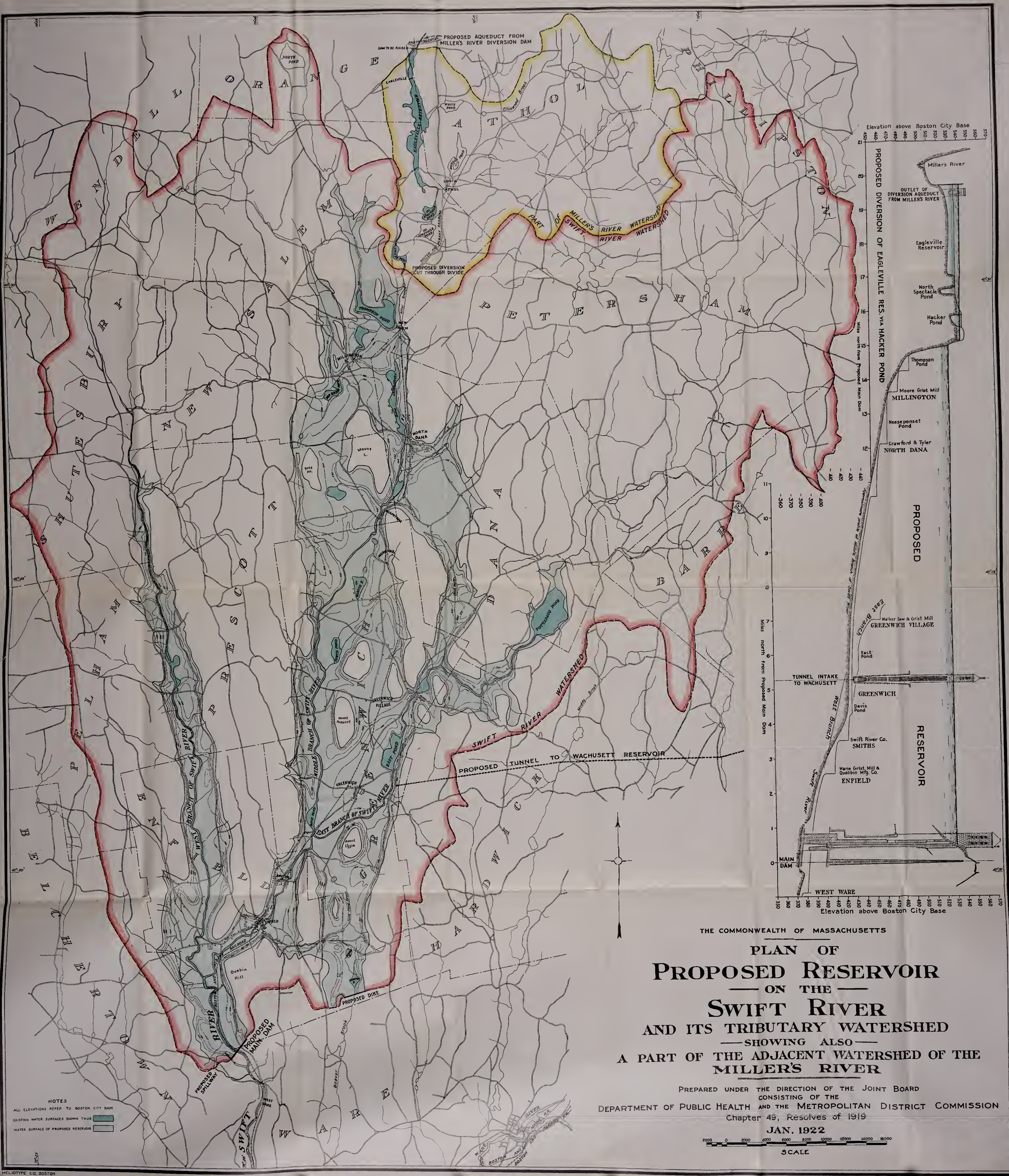
Location of Proposed Reservoir.

The results of the recent investigations show that a suitable location for a dam is found in the valley of the Swift River in the vicinity of the point where the boundary line between Enfield and Ware touches the Swift River about 3.5 miles below the village of Enfield and about 8 miles above the mouth of the river.

The conditions at the low point in the divide between the Swift and Ware rivers northeast of the main dam do not appear to be favorable for the construction of a dam or dike at that point within a reasonable limit of cost, but examinations in the valley of Beaver Brook show that a favorable site for a supplementary dam or dike is found at a comparatively narrow gorge in this valley about a mile below or south of the divide and a short distance north of the Enfield–Ware boundary line.

By the construction of this dam and dike it is practicable to create a reservoir with a maximum surface elevation at grade 530, or 135 feet above the high-water level of Wachusett Reservoir, and to deliver the water into Wachusett Reservoir by gravity through an aqueduct or tunnel about 25 miles in length.

The great reservoir thus created would have an area of 39 square miles, about half the size of Lake Winnipesaukee and six times that of the Wachusett Reservoir; its storage capacity of about 400,000,000,000 gallons would be six times that of the Wachusett Reservoir and equivalent approximately to the amount of water contained in the upper 10 feet in depth of Lake Winnipesaukee. While the reservoir would be high enough to deliver all of the water to the Wachusett Reservoir by gravity, it would be low enough to receive by gravity the flow of a large part of other important tributaries of the Connecticut River in central and western Massachusetts, of the Ware, the Quaboag, the Millers, the Deerfield and the West-


THE COMMONWEALTH OF MASSACHUSETTS
PLAN OF
PROPOSED RESERVOIR
— ON THE —
SWIFT RIVER
AND ITS TRIBUTARY WATERSHED
— SHOWING ALSO —
A PART OF THE ADJACENT WATERSHED OF THE
MILLER'S RIVER
PREPARED UNDER THE DIRECTION OF THE JOINT BOARD
CONSISTING OF THE
DEPARTMENT OF PUBLIC HEALTH AND THE METROPOLITAN DISTRICT COMMISSION
Chapter 49, Resolves of 1919
JAN. 1922
SCALE
NOTES
ALL ELEVATIONS REFER TO BOSTON CITY BASE
EXISTING WATER SURFACES SHOWN THUS
WATER SURFACE OF PROPOSED RESERVOIR
HELIOTYPE CO. BOSTON
PROPOSED DIVERSION OF EAGLEVILLE RES. VIA HACKER POND
Elevation above Boston City Base
Miles north from Proposed Main Dam
PROPOSED
RESERVOIR
PROPOSED AQUEDUCT FROM MILLER'S RIVER DIVERSION DAM
PROPOSED DIVERSION CUT THROUGH DIVIDE
PART OF MILLER'S RIVER WATERSHED
SWIFT RIVER WATERSHED
PROPOSED TUNNEL TO WACHUSETT RESERVOIR
TUNNEL INTAKE TO WACHUSETT
PROPOSED MAIN DAM
PROPOSED SPILLWAY
PROPOSED DIKE
Miller's River
OUTLET OF DIVERSION AQUEDUCT FROM MILLER'S RIVER
Eagleville Reservoir
North Spectacle Pond
Hacker Pond
Thompson Pond
Moore Grist Mill
MILLINGTON
Neeseponset Pond
Crawford & Tyler
NORTH DANA
Walker Saw & Grist Mill
GREENWICH VILLAGE
East Pond
GREENWICH
Davis Pond
Swift River Co.
SMITHS
Ware Grist Mill & Quabbin Mfg. Co.
ENFIELD
MAIN DAM
WEST WARE
WEST BRANCH OF SWIFT RIVER
MIDDLE BRANCH OF SWIFT RIVER
EAST BRANCH OF SWIFT RIVER
ORANGE
ATHOL
PHILLIPSTON
WENDELL
NEW SALEM
PETERSHAM
SHUTESBURY
PRESCOTT
DANA
BARRE
PELHAM
GREENWICH
ENFIELD
HARDWICK
BELCHERTOWN
WARE

field, — in all, the drainage from more than 1,000 square miles, or about one-eighth of the total area of the State, if it should ever be deemed desirable in the future to utilize the flood waters from all of these watersheds in connection with this reservoir.

Conditions affecting the Quality of the Water.

The watershed of the Swift River is singularly well adapted for water supply uses. The population within the watershed has never been large and has been diminishing gradually for the greater part of a century, and in recent years at an accelerating rate. The towns which are largely or wholly included within this watershed above the proposed dam, and their population in United States census years from 1850 to 1920, are shown in the following table: —

Population, 1850–1920.

	1850.	1860.	1870.	1880.	1890.	1900.	1910.	1920.
Enfield	1,036	1,025	1,023	1,043	952	1,036	874	790
Dana	842	876	756	736	700	790	736	599
New Salem	1,253	957	987	869	856	807	639	512
Pelham	983	748	673	614	486	462	467	503
Greenwich	838	699	665	633	526	491	452	399
Prescott	737	611	541	460	376	380	320	236
Shutesbury	912	798	614	529	453	382	267	242
Petersham	1,527	1,465	1,335	1,109	1,050	853	757	642
Totals	8,128	7,179	6,594	5,993	5,399	5,201	4,512	3,923

NOTE. — In addition, portions of the towns of Phillipston, Athol, Orange, Wendell, Hardwick, Belchertown and Barre are included, but these areas do not include thickly settled parts of any of these towns.

At the present time the population of these towns averages 21.6 persons per square mile, located mainly in the small villages in the valleys of the principal streams. Along the main or middle branch of the Swift River, and within the area that would be flowed by the proposed reservoir, there is a total fall of about 90 feet from the headwaters near Thompson Pond to the tailrace of the mill in Enfield. About 57 feet of this total fall is developed by small dams, none over 10 to 12 feet high, for the benefit of several mills and factories, though the more important of these mills have not been in operation during the past year. There is very little pollution of the streams in this watershed either by sewage or manufacturing waste, and practically none outside the area which would be cleared and flowed by the proposed reservoir.

The quality of the water of the main streams in the Swift River valley has been determined by analysis at frequent intervals during the past two years. The results show that the water is clear, soft, comparatively low in color among the streams of the State, and of excellent quality in all respects for water supply uses. It might be supposed that so extensive an area of nearly level land as is found in the lower valleys of this watershed would contain extensive swamps, but such is not the case. In the ridges which border the valleys and in the isolated hills and small mountains rising from the valley levels rock is found very generally, and the soil of the higher lands consists largely of fine material, generally hardpan, overlaid with a considerable depth of loam. In the valleys, on the contrary, within the area that would be covered by the proposed reservoir, the soil is for the most part coarse and porous, with generally a thin surface layer of sandy loam, while the areas of swamps containing deep peat deposits are exceedingly few and small.

Combination of Flow of Swift and Ware Rivers in One Storage Reservoir.

The total drainage area of the proposed reservoir above the proposed dam and dike, including a small area in the Beaver Brook valley, a tributary of the Ware River, is about 186 square miles.

The conditions in the valley of the Swift River below the proposed main dam differ from those in the valley of the Ware River below Coldbrook, since the manufacturing industries are fewer in number and do not use large quantities of water for washing and industrial processes. Neither are there any large towns or villages which discharge untreated sewage or factory wastes containing large quantities of organic matter into the river. In fact, analyses of the waters of the Swift River indicate that above the point where it is joined by the Ware the Swift River receives very little pollution of any kind.

Conservation of Flood Waters by Diverting only the Higher Flows from Large Areas.

It is essential that an additional water supply be secured for the Metropolitan District from the best available source, but it is also most important that that supply be obtained at the minimum cost and with the least possible injury to the water powers of the State and its other important interests and industries, and with the least disturbance practicable to any of its inhabitants.

The diversion of practically the entire flow of the Ware and Swift rivers would provide a sufficient water supply for the Metropolitan Water District for a very long time in the future, but it is not desirable to divert all of the flow from the Ware and Swift rivers for water supply purposes, for reasons which have been stated previously in connection with the discussion of diversions from the Ware River watershed.

The distribution of the rainfall in New England is such that the greater part of the water yielded by the rainfall and the melting snows of winter passes off in the streams in the winter and spring, and, while the river valleys are ordinarily inundated for a few weeks in the latter period, the streams usually shrink to comparatively small dimensions for many months in the summer and fall. The Swift and Ware rivers are no exception to this rule. Measurements of the Swift River at a measuring station maintained for several years at West Ware, a short distance below the proposed main dam in this valley, have shown a maximum flow in a period extending from August, 1912, to December, 1921, as high as 8,000,000 gallons per square mile per day, and a minimum as low as 76,000 gallons per day. Wider variations would no doubt have been shown if longer records were available. There are ordinarily many weeks in the winter and spring, and often periods in the summer and autumn, in some years when the flow of water exceeds the capacity of the wheels in the power plants on the Swift and

Ware rivers and on the Chicopee River below them, and water runs to waste over all of the dams on these streams. On the other hand, in the summer and autumn the flow generally falls below the capacity of the wheels, and a part of the power necessary for operating machinery in the factories and mills must in many cases be obtained from other sources or from auxiliary steam plants maintained for this purpose.

The diversion of the water of the highest flows, if an adequate storage reservoir were available, would diminish the freshets which interfere at times with the operation of power plants and cause injury in other ways. The storage afforded by the proposed reservoir in the Swift River valley would be so great that with that reservoir it would be practicable so to regulate the discharge into the Swift River that instead of the occurrence of variations of flow ranging from 76,000 to 8,000,000 gallons per square mile per day, a nearly uniform quantity of water could be discharged to the mills below at all times at all seasons of the year alike, in years of excessive rainfall and in years of drought, with comparatively little waste in proportion to the whole quantity used.

If all the water should be diverted for municipal supply, the damage might not be serious in the beginning, but it would have to be paid for, though a part of the water would still be available for many years for the use of its former owners. On the other hand, by taking advantage of the storage afforded by a great reservoir in the Swift River valley, and retaining therein only the higher flows in the Swift and Ware rivers above the quantities which are required by the majority of the industrial and power plants, the water flowing in periods of excess could be diverted for water supply uses and the remaining water allowed to flow past the dams in varying quantities as it does to-day, or in such quantities and at such times as might be mutually agreed to be to the best advantage of those who use the water for power. In this way the damages for water power would be materially reduced and the great variations in the natural flow of the river could be regulated.

If the yield of the Swift River watershed alone were depended upon for the water supply of the Metropolitan Water District and the municipalities which may require water therefrom, it would be necessary to take not only the freshet flows but a large portion of the lower flows, reducing considerably the flow of water in the river below the point of diversion and increasing the expense for damages to water powers.

By combining the flow of the Ware River above Coldbrook with that of the Swift, less encroachment on the flow of the rivers would be necessary and enough water could be obtained for the supply of the district for many years if only those flows in excess of about 0.8 of a cubic foot per second per square mile of watershed, or about 500,000 gallons per square mile per day, were taken for municipal uses, leaving the flow when a less amount was running to pass down the rivers as it does to-day, but if a still larger area of watershed than that of the Swift and Ware rivers combined were made tributary to the proposed Swift River Reservoir, the proportion of the flows of all the watersheds which it would be necessary to take for water supply requirements would be still further reduced.

Practicability of Utilizing a Part of the Flow of the Millers River.

The Millers River was not carefully considered at the time of the investigation of 1895 as a possible source of water supply because of danger of pollution of the water from one or two towns in its watershed. A further consideration of the possible use of this watershed shows that the larger of these towns is but little greater in size than the largest municipality within the present metropolitan watershed areas, and if the largest of the towns in the latter watersheds, which is situated at the head of the Sudbury Reservoir, can be so dealt with as to prevent its being a menace to the metropolitan water supply at the present time, it seems possible that the drainage from towns on the Millers River might also be cared for satisfactorily, in view of the circumstances, in case it should be desirable to use that stream for water supply purposes. Further studies have accordingly been made of the feasibility of using the water of Millers River in connection with that of the Ware and Swift so as to decrease the proportion of the flow to be diverted from all three watersheds. These studies show that by combining the three watersheds it will be necessary to divert only the flows in excess of 1.2 cubic feet per second per square mile, or about 775,000 gallons per square mile per day, in order to meet the requirements of the district and of municipalities which may be dependent thereon for many years to come.

The Millers River Watershed.

The Millers River rises in the hills of Ashburnham and Gardner and flows in a general westerly course to the Connecticut River above Turners Falls, its watershed lying contiguous to the northerly boundaries of the watersheds of the Ware and Swift rivers. Above the dam at South Royalston, where the elevation of the river is about 817, the fall of the main stream and also of its principal tributary, the Otter River, is comparatively small for many miles, but below South Royalston the river falls rapidly to the dam at Athol, the elevation of which is about 577 feet. Surveys and investigations show that it is practicable to divert the water of this stream into the Swift River watershed by gravity if taken at any point above Athol. The drainage area of the Millers River at the mill pond just above Athol is about 201 [1] square miles, about 51 square miles of which lie within the limits of the State of New Hampshire, chiefly in the towns of Rindge and Fitzwilliam, one of the villages in the latter town being situated within this watershed. The towns which are mainly within the watershed in Massachusetts are Gardner, Winchendon, Templeton and Phillipston, together with considerable portions of Ashburnham, Royalston and Athol. The portion of the town of Royalston included is very small in proportion to the whole area of the town, but this part contains the village of South Royalston. The portion of the town of Athol included, however, is practically uninhabited, and there is very little population within the portion of the drainage area which lies within the limits of the town of Ashburnham. The population of the towns on the watershed in census periods in the last thirty years is shown in the following table: —

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[1] Including watersheds diverted for public water supplies of Ashburnham, Winchendon, Gardner and Athol.

Population of Towns mainly within the Watershed of Millers River.

	1890.	1895.	1900.	1905.	1910.	1915.	1920.
Massachusetts.							
Gardner	8,424	9,182	10,813	12,012	14,699	16,376	16,971
Winchendon	4,390	4,490	5,001	5,933	5,678	5,908	5,904
Templeton	2,999	2,915	3,489	3,783	3,756	4,081	4,019
Phillipston	502	460	441	442	426	390	354
Royalston	1,030	890	958	903	792	862	819
Totals	17,345	17,937	20,702	23,073	25,351	27,617	28,067
New Hampshire.							
Fitzwilliam	1,122	–	987	–	1,148	–	962
Rindge	996	–	855	–	706	–	643
Totals	2,118	–	1,842	–	1,854	–	1,605
Grand totals . . .	19,463	–	22,544	–	27,205	–	29,672

Of the foregoing Massachusetts towns only Gardner and Winchendon are provided with public water supplies, and only Gardner with a system of sewers. The sewage of the town of Gardner is treated upon two groups of filter beds located southwest of the town in the valley of the Otter River. Plans have been made for a sewage disposal system for the town of Winchendon, the filter beds to be located near the Millers River, west of the town. There is no doubt that the sewage of these towns and villages could be effectively purified, and after thorough disinfection discharged into the rivers without seriously affecting the quality of the water for water supply purposes, but considering the excellent quality of the water obtainable from the other watersheds and its freedom from danger of pollution, it is not desirable to use the Millers River in connection therewith unless the sewage effluents can be wholly diverted from its watershed. A study of the feasibility of removing these effluents after purification indicates that by means of sewers aggregating about 22½ miles in length it would be practicable to collect effluents from sewage filters in Gardner and Winchendon and the smaller villages in Templeton and Royalston and discharge them into the Millers River at any desired point below the point of diversion of the waters of that stream.

Except for the towns and villages mentioned, from which the sewage effluents could be removed from the stream as suggested, the watershed of the Millers River is sparsely populated. Furthermore, the water is soft and in other respects of good quality for water supply purposes, and while it is considerably colored, the color differs little from that of the Ware River at Coldbrook.

Proposed Diversion of Water from Millers River above Athol via Eagleville Reservoir.

The results of this investigation having shown that it is feasible to remove the objectionable pollutions from that portion of the Millers River watershed which might be diverted into a reservoir in the Swift River valley by gravity, a further study was made of practicable means of diversion. A number of plans have been considered, the most favorable of which appears to be the construction of an aqueduct from the river above Athol along the southerly side of the river, partly in tunnel, to a mill pond on a small stream which passes through the villages of Partridgeville and Eagleville and enters the Millers River from the south at a point about 3 miles below Athol.

This mill pond or reservoir is created by the dam at Partridgeville and drains an area of about 19.5 square miles. The Eagleville Reservoir extends some 3 miles in a southerly direction from the dam and at its southerly end is within about 2 miles of the upper end of the Swift River Reservoir. It was found to be practicable, by raising the dam at Partridgeville about 12 feet and excavating a channel through the divide between the Millers and Swift river watersheds, which is very low in this vicinity, to divert the water from these 19.5 square miles, which now flows to the Millers River, into the Swift River watershed.

As the Millers River falls rapidly above Athol, its waters can be diverted at any desired level above that town and discharged by gravity into the proposed enlarged and elevated reservoir above Partridgeville and thence diverted into the proposed reservoir on the Swift River. The tunnel and aqueduct would have an average diameter of about 11.5 feet and would be large enough to carry all the flood flows from the drainage area above Athol up to and including flows of 5 cubic feet per second per square mile in excess of the normal undiverted flow of the river. A part of the water of the highest freshets could not be utilized, but the quantity lost in average years would not be considerable. The drainage area which can thus be diverted from the Millers River, including the small area draining into the Eagleville Reservoir amounting to 19.5 square miles, would be about 220 square miles, and with this addition the total area of watershed tributary to the proposed reservoir in the valley of the Swift River would be 506 square miles, or nearly five times the area draining into the Wachusett Reservoir.

Advantages of Utilizing the Higher Flows of the Swift, Ware and Millers Rivers combined.

The advisability of using water from the Millers River in connection with the proposed reservoir in the valley of the Swift River, in view of the fact that the quality of the water can be rendered satisfactory within a reasonable outlay, depends largely upon the cost of the improvements in the watershed of the Millers River and the expense of diversion works and of damages for the water diverted as compared with the probable damages for taking a larger proportion of the flow from the watersheds of the Swift and Ware rivers.

Estimates of the cost of utilizing the Millers River compared with the cost of taking a greater quantity of water from the Swift and Ware rivers, based upon the results of preliminary surveys and investigations in the watershed of the Millers River and careful estimates of the probable mill damages, indicate that it will make very little difference in the cost of works for supplying water from these sources to the Metropolitan Water District, whether the Millers River is utilized and the diversion of water from the Swift and Ware rivers is therefore confined to higher flows, or whether a greater proportion of the flow of the Swift River and Ware River is utilized and the Millers River omitted from the proposed plan.

In view of the results of these estimates, since it would make no practical difference in the cost of the works to the Metropolitan Water District, it would undoubtedly be best to select the scheme which would have the least influence in reducing, no matter to how small a degree, the available water power of the State. The most reasonable plan to adopt under the circumstances appears to be the utilization of the freshet flows of the Millers River, in addition to those of the Ware and the Swift, in connection with the proposed reservoir in the valley of the Swift River.

Summary of Available Yield of Proposed New Sources, taking the Higher Flows of the Ware, Swift and Millers Rivers.

The estimated amount of diversion from each watershed under the proposed plan for diverting all the flows in excess of 1.2 cubic feet per second per square mile is as follows: —

River.	Drainage Area (Square Miles).	Safe Yield based on Rainfall of 1897–1920 (Million Gallons per Day).
Swift	186.0	87
Ware above Coldbrook	100.0	47
Millers above Athol	201.0	87
Millers River, Eagleville Reservoir watershed	19.5	9
Totals	506.5	230
Losses from various causes	–	28
Net yield	–	202

In other words, a supply of about 200,000,000 gallons per day, can be obtained from these watersheds by collecting and storing the flows above 1.2 cubic feet per second per square mile. These diversions would be made in general only in the winter and spring months, and, judging from the records of the flow of the streams in this region there would be no interference with the normal flow of either the Swift, the Ware or the Millers rivers during about 57 per cent of the time. There are a number of mills and power companies along the Swift, Ware and Millers rivers, and other rivers below the proposed points of diversion of these streams, that have developed their power plants so as to use a portion of the flood flows for the development of power, and the estimates of cost include, it is believed, ample allowance for damages for all water-power developments.

Rainfall as the Basis of Available Yield.

In connection with these investigations a study has been made of the rainfall in the watersheds of the Ware, Swift and Millers rivers, and the probable yield of these watersheds as shown by available data. Very few long-term rainfall records have been maintained in either of these valleys, though there are a number in their general neighborhood. A study of the available records has been supplemented with a consideration of records of measurements of flow of the Millers River since July, 1915, and of the Ware and Swift Rivers since August, 1912, as carried on by the United States Geological Survey in co-operation with the Department of Public Works in Massachusetts. These records have been compiled and compared with the records of rainfall and flow of the Nashua River at Clinton, which have been continuous and carefully kept for a period of twenty-five years. The results indicate in general that on the easterly and northeasterly sides of the Ware River and Swift River watersheds considered as a single area the rainfall is probably somewhat less than on the South Branch of the Nashua above Clinton, and that the amount is still smaller on the southerly and westerly sides of these watersheds, though so far as these available records show there is a considerable difference in distribution of rainfall in the summer months in the western and southwestern districts, the amounts being slightly greater in the summer, and in the winter months less, than on the Wachusett watershed. On the north, and in the watershed of the Millers River, the available records indicate that the rainfall is less than in the areas farther south, and the northwesterly sections of these watersheds probably have an annual rainfall still smaller in proportion to that upon the Nashua River watershed, though the maximum difference is probably about 10 per cent, the difference being somewhat more marked in winter than in summer. Taking the rainfall observations in connection with the flow of the streams as shown by available measurements, an estimate covering a considerable period of years shows that by taking all of the flows of the Ware, Swift and Millers rivers in excess of 1.2 cubic feet per second per square mile of watershed, and allowing the remainder to continue to flow in the streams, enough water can be obtained to fill the proposed reservoir in the Swift River watershed within a reasonable time. Moreover, the new supply could be drawn upon at the same time, so that together with the old sources there would be enough water for the district for at least thirty years in the future.

These estimates are based upon the assumptions that work upon the construction of the proposed reservoir on the Swift River will be carried far enough to make it practicable to begin the filling of the reservoir by about 1934, and cover the contingency of the occurrence of a period of low rainfall should such a period occur immediately following that year. Under this plan the available yield of the sources of water supply of the Metropolitan Water District would be increased by as much as 200,000,000 gallons per day; that is, the total yield would be increased to 2.3 times that of the present sources of supply. In the construction of the Wachusett system the yield was increased to about 2.8 times that of the existing Sudbury and Cochituate works.

Proposed Plan adapted to supply Water to the City of Worcester.

The city of Worcester, as stated previously in this report, has presented a report to the Legislature outlining a plan for an additional water supply for that city to be taken from Quinepoxet Pond and a neighboring stream in the Wachusett watershed, whence the water is to be pumped into Kendall Reservoir of the Worcester water works system. This plan includes a provision for constructing later a reservoir above Quinepoxet Pond when a further supply becomes necessary. The quantity of water obtainable in a dry year under this plan in the beginning is estimated in that report at 10,000,000 gallons per day or a little more than 60 per cent increase over the safe yield of present sources. Hence if this plan were followed, a further additional supply would become necessary after about twenty years.

Instead of taking water from the Quinepoxet source in the Wachusett watershed, water could be pumped from one of the shafts of the proposed tunnel, where it would pass beneath one of the main tributaries of the Pine Hill Reservoir, now under construction, and be discharged directly into this tributary stream through which the water would flow to the reservoir.

Under the plan of supplying water to the Metropolitan Water District from the Ware River and beyond, power would be generated at the Wachusett terminal of the tunnel soon after its completion. There would be ample power from this source for pumping the water supply of the city of Worcester from the proposed tunnel should that city join in this plan. Furthermore, it is proposed to divert the Quinepoxet River into the tunnel above Wachusett Reservoir, where its drainage area is about 36 square miles, and to utilize the fall of this water for power. If before the Swift River works were completed Worcester should need water at any time when the Ware River flow was below the diversion limit, and none could be supplied from that source, the supply to the pumps could be maintained temporarily from the Quinepoxet River which would keep the tunnel full at all times.

There is no doubt that by the plan for pumping directly from the tunnel Worcester would obtain a supply as satisfactory in all respects for the use of the city as the water obtainable from present sources, or from these sources supplemented by pumping from Quinepoxet Pond in accordance with the recommendation in Senate No. 346, 1920. If, following the latter recommendation, water from Quinepoxet Pond were pumped into Kendall Reservoir by way of the Pine Hill intake, that reservoir would receive a supply of water of low color. If, on the other hand, the water supply of the city of Worcester should be pumped directly from the tunnel into a tributary of the Pine Hill Reservoir, that city would receive a supply with a color about 10 per cent above that now tributary to the Wachusett Reservoir, but this water would pass through the new Pine Hill Reservoir and be well bleached in passage, in the same way that the present metropolitan supply is bleached in passage through Wachusett Reservoir to an almost colorless effluent. The use of the water of the Ware River alone would be temporary in any case, since eventually the tunnel would be extended to the Swift River and receive a practically colorless supply.

There is still another method of increasing the water supply of the city of Worcester, especially in view of the fact that the 30-inch force main which was laid in 1911 from the Wachusett Reservoir to the "Summit," or northerly portion of the city's distributing system, is still in place. For a relatively small sum pumps could again be installed at the Wachusett Reservoir which, with such enlargements of the works as might later become necessary, could pump any desired quantity from that source directly into either the high or low service mains of the city.

By either of these two latter plans the construction and maintenance of the works necessary for pumping water from Quinepoxet Pond could be avoided and the construction of the proposed reservoir above that pond, a few years hence, eliminated. While the cost of pumping either from the tunnel shaft or from the Wachusett Reservoir would be greater than from Quinepoxet Pond, the net cost of a water supply to the city of Worcester under either of these two plans now proposed would be less. Furthermore, if water were taken either from the tunnel or from Wachusett Reservoir a supply would be available at the point of diversion which would be adequate for a very long time in the future without the construction of additional reservoirs or collecting works.

The choice between these two plans for an additional water supply for Worcester, either from the tunnel shaft or from Wachusett Reservoir, will depend to a large extent upon the financial arrangements that may be made between Worcester and the Metropolitan Water District, and can be finally determined only in the working out of the details of the extension of the water works system of the Metropolitan Water District.

Possibility of Diverting Flood Flows from the Quaboag River.

The Quaboag River is the most southerly of the three rivers which unite to form the Chicopee River in the town of Palmer, and joins the Chicopee at the village of Three Rivers less than a mile below the confluence of the Swift and Ware rivers. The drainage areas of these tributaries at their points of confluence are as follows: —

	Square Miles.
Swift	213
Ware	221
Quaboag	210

The elevation of the Quaboag River at a point above the village of Warren is such that it would be practicable to divert the higher flows into the Swift River Reservoir through an aqueduct about 10 miles in length. The drainage area of the Quaboag River at this point of possible diversion is 137 square miles, which includes all or considerable portions of the towns of Spencer, North Brookfield, Brookfield, West Brookfield, Paxton and New Braintree. The aggregate population of these towns in 1920 was 13,397. The population has decreased 5,921 in the past thirty years.

There are sewerage systems in Spencer and North Brookfield, but there is no doubt that it would be practicable without excessive cost to care for the effluent from these works in a satisfactory manner if the river were used as a source of water supply. There is no doubt that the freshet flows of this stream could be utilized in connection with the Swift River project should it be found desirable to do so in the future, unless conditions change materially from those existing in this watershed at the present time.

Proposed Plan adapted to Future Extension to the Deerfield and Westfield River Watersheds.

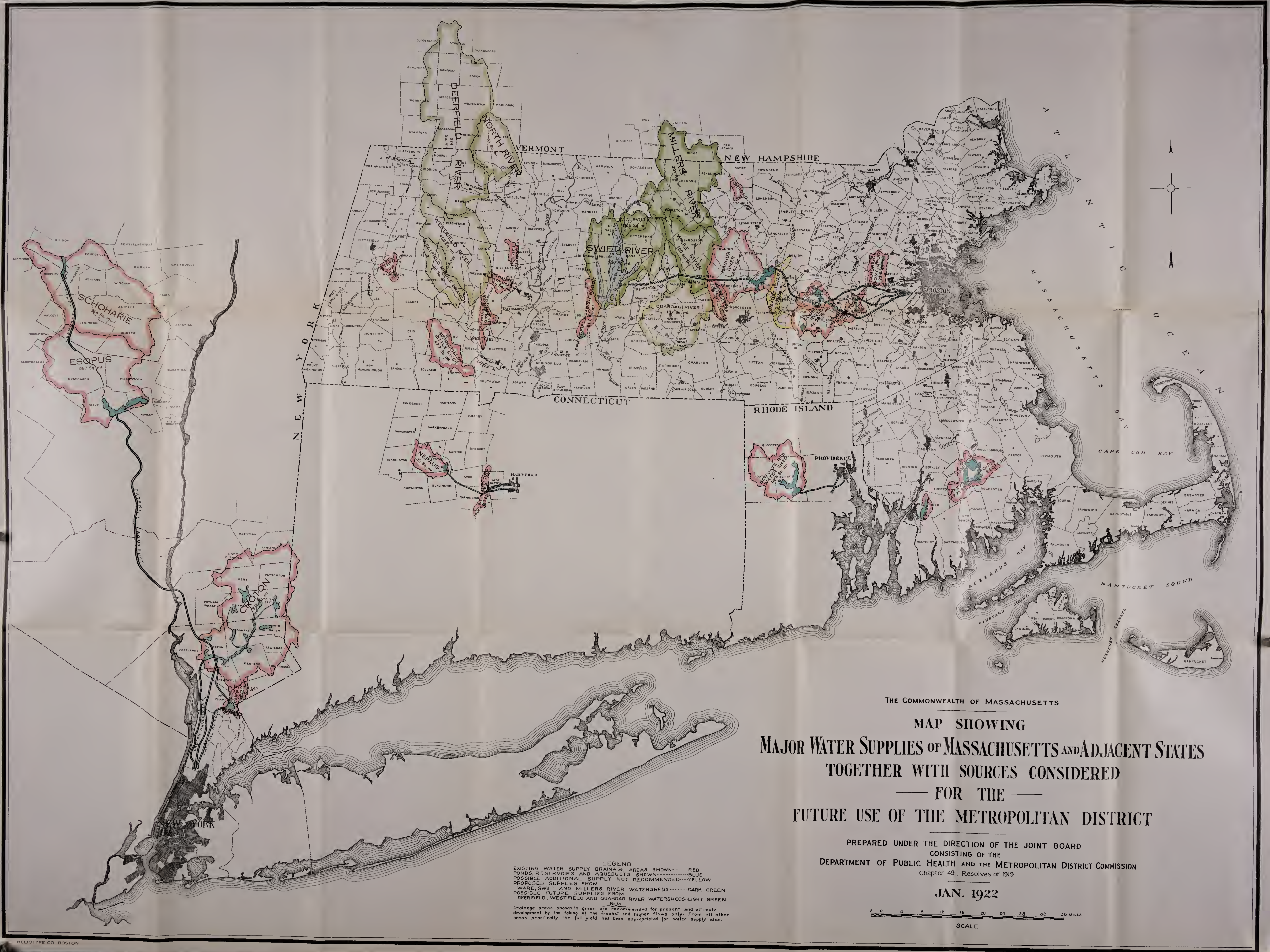
As previously indicated, it is possible also to divert into the Swift River Reservoir by gravity, through an aqueduct about 25 miles in length, both the waters of the Deerfield River and those of its northerly tributary above Shelburne Falls, by constructing a diversion reservoir in that neighborhood of sufficient elevation for the purpose, thus making it practicable to divert into the Swift River Reservoir the water from an additional drainage area of over 450 square miles. Attention was called also to the practicability of diverting water from the East and Middle branches of the Westfield River into the Swift River watershed through an aqueduct and tunnel of about the same length as in the case of the Deerfield River. With the rapid growth of population in the Connecticut River valley in Springfield, Chicopee, Holyoke, Westfield and adjacent towns, any diversion of water of the Westfield watershed should be subject to adequate reservations to meet the growing needs of the population of that region.

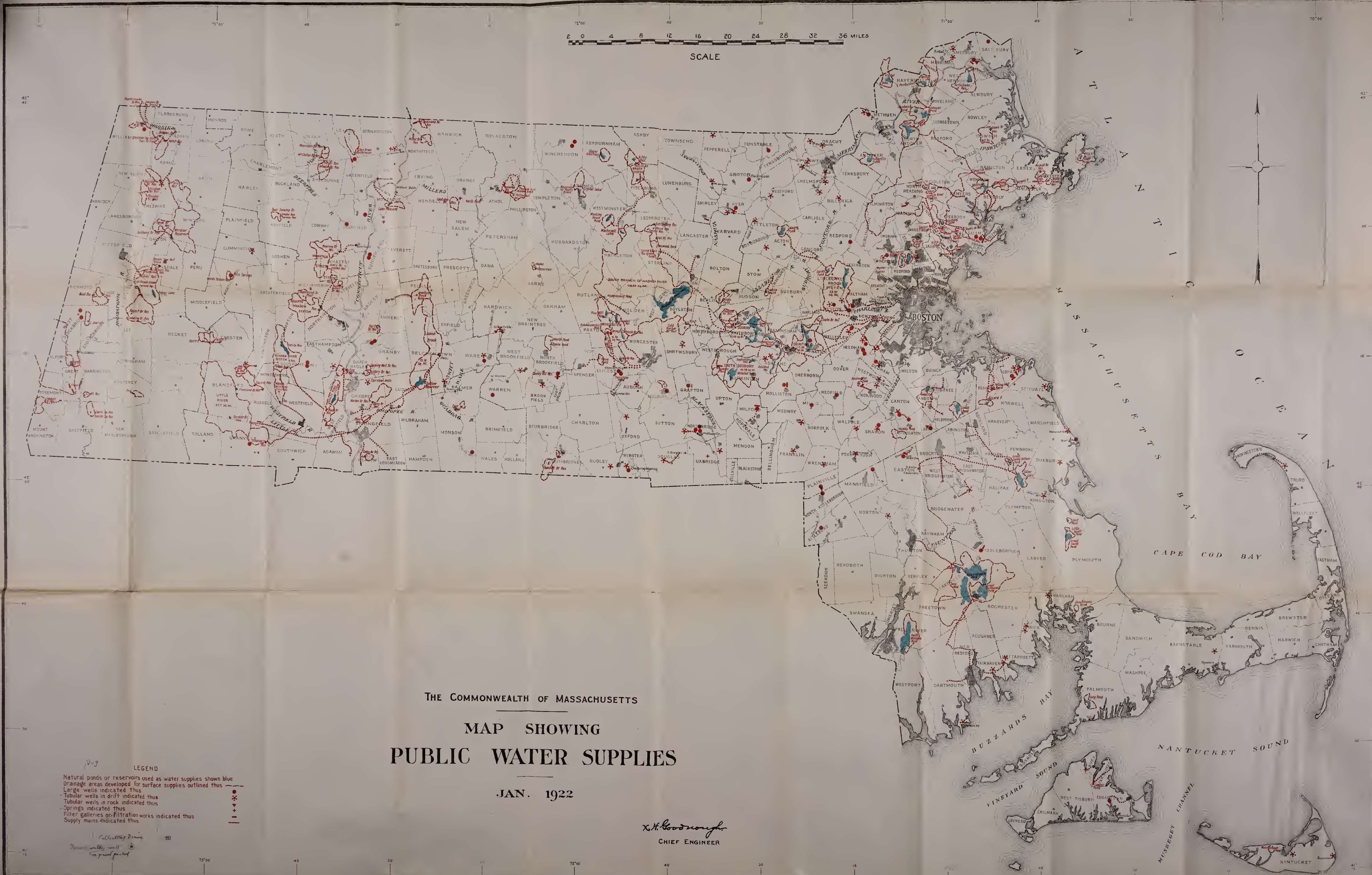
The Deerfield and Westfield rivers derive their flow from mountainous watersheds sparsely inhabited by a population which has been decreasing in numbers for many years, and there are few industries in those portions of these river valleys from which water could be diverted into a reservoir on the Swift River by gravity, and no present probability that large industries will be established there in the future. Such value as these streams possess, as sources of water supply for power, is being developed at the present time for mills in the lower parts of these valleys, and, in the case of the Deerfield River, for transmission to more populous regions.

Large Additions to the Supply possible by Taking the Flood Flows only from other Watersheds.

The fact that additional diversions from other watersheds are possible, if desired at some future time, is to be taken into account in considering any scheme for water supply in connection with the Swift River Reservoir.

It is not essential, however, at the present time to consider the use of the Deerfield, the Westfield or the Quaboag River in connection with the Swift River Reservoir, except to note that the flow from a very large drainage area in the Deerfield valley, and from a considerable area in the Quaboag and possibly the Westfield valley, could be diverted into the proposed reservoir on the Swift River watershed by gravity, and no further investigation has been made of these sources. If the


THE COMMONWEALTH OF MASSACHUSETTS
MAP SHOWING
MAJOR WATER SUPPLIES OF MASSACHUSETTS AND ADJACENT STATES
TOGETHER WITH SOURCES CONSIDERED
FOR THE
FUTURE USE OF THE METROPOLITAN DISTRICT
PREPARED UNDER THE DIRECTION OF THE JOINT BOARD
CONSISTING OF THE
DEPARTMENT OF PUBLIC HEALTH AND THE METROPOLITAN DISTRICT COMMISSION
Chapter 49, Resolves of 1919
JAN. 1922
0 4 8 12 16 20 24 28 32 36 MILES
SCALE
LEGEND
EXISTING WATER SUPPLY DRAINAGE AREAS SHOWN-----RED
PONDS, RESERVOIRS AND AQUEDUCTS SHOWN------------BLUE
POSSIBLE ADDITIONAL SUPPLY NOT RECOMMENDED---YELLOW
PROPOSED SUPPLIES FROM
WARE, SWIFT AND MILLERS RIVER WATERSHEDS-------DARK GREEN
POSSIBLE FUTURE SUPPLIES FROM
DEERFIELD, WESTFIELD AND QUABOAG RIVER WATERSHEDS--LIGHT GREEN
Note
Drainage areas shown in green are recommended for present and ultimate development by the taking of the freshet and higher flows only. From all other areas practically the full yield has been appropriated for water supply uses.
VERMONT
NEW HAMPSHIRE
NEW YORK
CONNECTICUT
RHODE ISLAND
ATLANTIC OCEAN
MASSACHUSETTS BAY
CAPE COD BAY
BUZZARDS BAY
NANTUCKET SOUND
VINEYARD SOUND
BOSTON
PROVIDENCE
HARTFORD
NEW YORK
SCHOHARIE
ESOPUS 257 Sq. mi.
CROTON
DEERFIELD RIVER
NORTH RIVER
MILLERS RIVER
SWIFT RIVER
WARE RIVER
QUABOAG RIVER
NEPAUG
HELIOTYPE CO. BOSTON

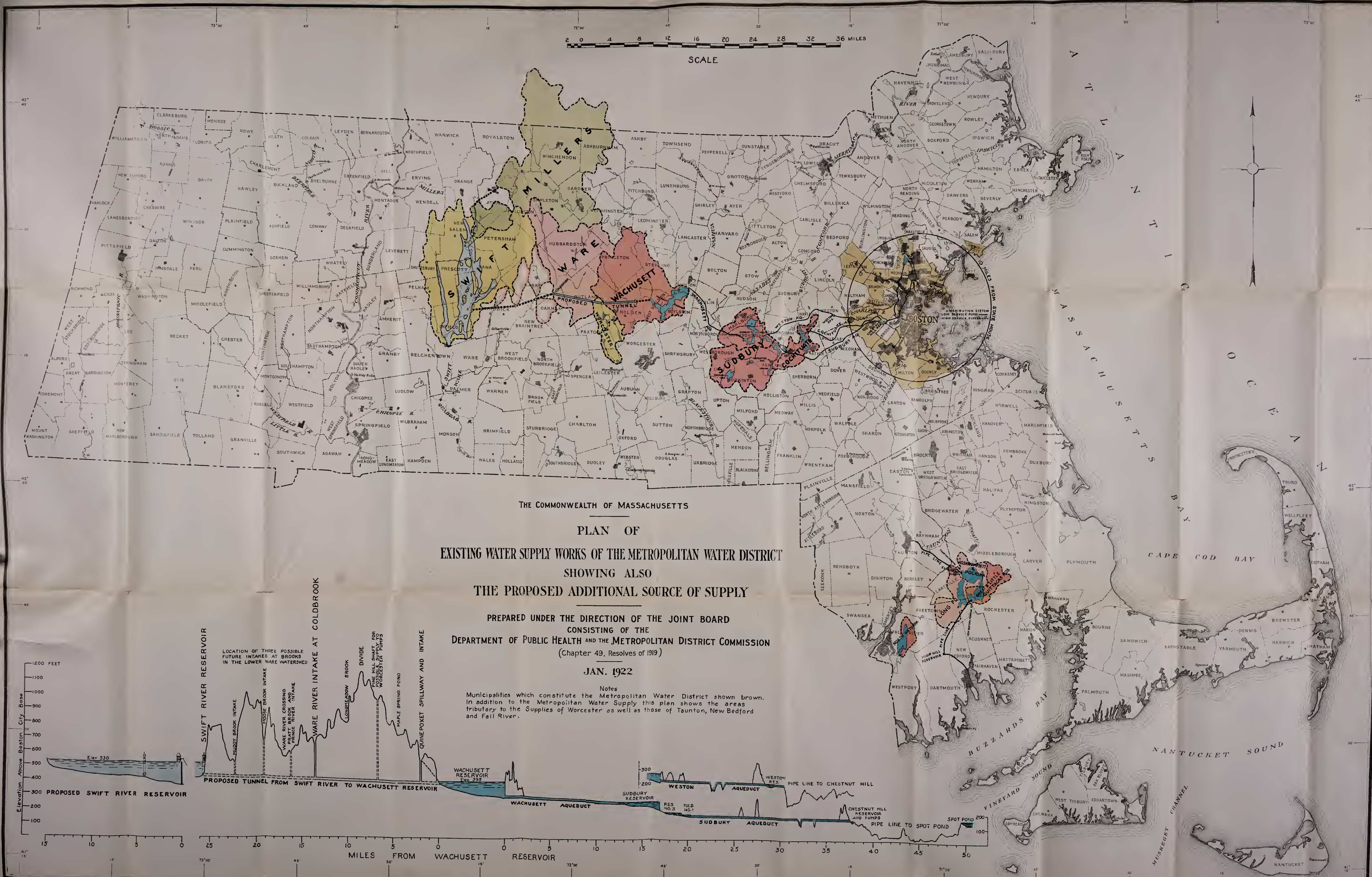


THE COMMONWEALTH OF MASSACHUSETTS

MAP SHOWING PUBLIC WATER SUPPLIES

JAN. 1922

X. H. Goodnough
CHIEF ENGINEER


THE COMMONWEALTH OF MASSACHUSETTS
PLAN OF
EXISTING WATER SUPPLY WORKS OF THE METROPOLITAN WATER DISTRICT
SHOWING ALSO
THE PROPOSED ADDITIONAL SOURCE OF SUPPLY
PREPARED UNDER THE DIRECTION OF THE JOINT BOARD
CONSISTING OF THE
DEPARTMENT OF PUBLIC HEALTH AND THE METROPOLITAN DISTRICT COMMISSION
(Chapter 49, Resolves of 1919)
JAN. 1922
Notes
Municipalities which constitute the Metropolitan Water District shown brown. In addition to the Metropolitan Water Supply this plan shows the areas tributary to the Supplies of Worcester as well as those of Taunton, New Bedford and Fall River.
SCALE
36 MILES
ATLANTIC OCEAN
MASSACHUSETTS BAY
CAPE COD BAY
NANTUCKET SOUND
BUZZARDS BAY
VINEYARD SOUND
MUSKEGET CHANNEL
SWIFT
MILLERS
WARE
WACHUSETT
SUDBURY
COCHITUATE
BOSTON
PROPOSED TUNNEL
PROPOSED SWIFT RIVER RESERVOIR
PROPOSED TUNNEL FROM SWIFT RIVER TO WACHUSETT RESERVOIR
SWIFT RIVER RESERVOIR
LOCATION OF THREE POSSIBLE FUTURE INTAKES AT BROOKS IN THE LOWER WARE WATERSHED
WARE RIVER INTAKE AT COLDBROOK
DIVIDE
QUINEPOXET SPILLWAY AND INTAKE
WACHUSETT RESERVOIR
WACHUSETT AQUEDUCT
SUDBURY RESERVOIR
SUDBURY AQUEDUCT
WESTON AQUEDUCT
PIPE LINE TO CHESTNUT HILL
CHESTNUT HILL RESERVOIR AND PUMPS
PIPE LINE TO SPOT POND
SPOT POND
Elevation Above Boston City Base
MILES FROM WACHUSETT RESERVOIR

Metropolitan Water District and the populations dependent upon it for water continue to grow, the time may come when more water will be required, and it will then be possible to divert into the Swift River Reservoir the surplus flows of other watersheds, still using only the higher flows and thus avoiding injury to the rivers below and the industries dependent upon them for water for power and other uses.

PART IV. THE PROPOSED WORKS FOR EXTENDING THE METROPOLITAN WATER DISTRICT SUPPLY AND THEIR COST.

Main Dam and Beaver Brook Dike of the Proposed Swift River Reservoir.

The proposed site of the main dam is at the boundary between Enfield and Ware approximately as shown on the accompanying map. At this point, as at all the other sites examined in this region, the bedrock is covered with a deep deposit of drift, porous and water-bearing, and very variable in quality, and a form of construction carried to bedrock will be required. The proximity of great quantities of suitable material indicates that an earthen dam of ample dimensions with a core wall of impervious material carried to the bedrock will be the most appropriate type of dam under the existing conditions. Enough borings have been made to indicate closely the probable bedrock profile across the valley, and the ends of the dam will be in rock hills on either side. Beyond the rocky hill at the westerly end of the dam is an excellent location for a spillway and discharge channel which would be in rock and would discharge into the river through an outlet channel well below the dam and safe from possible damage, either to the dam or its appurtenances or to property in the valley below.

Explorations at the head of the valley of Beaver Brook with a view to the location of a dike at the low point in the divide between the Swift and Ware rivers indicate that the conditions there are unfavorable for the ordinary methods of dike construction, since the material overlying the rock, while varying from place to place, is to a large extent exceedingly porous. Furthermore, it appears well-nigh impracticable to excavate for reconstruction a suitable cut-off for a dike in this location. A more favorable site is found in the valley of Beaver Brook about a mile south of the divide, where the conditions are similar to those at the proposed site of the main dam in the valley of the main river. There is a similar mixture of porous and water-bearing materials and many boulders over the underlying rock, and here also, as at the main dam, a rock wall rises steeply from the floor of the valley on the west side, while on the east side the rock wall is more irregular in contour and much less steep. The deposit of loose water-bearing materials lying over the rock will require excavation, and a watertight core wall will be required at this location as at the main dam. The preliminary estimates provide for a similar form of construction as at the main dam.

Some of the principal dimensions of the proposed structures are shown in the following table: —

Dimensions of Main Dam.	Feet.
Elevation of flow line above present surface of river	147
Elevation of flow line above bottom of rock gorge	253
Width of gorge at flow line	2,700
Height of top of dam above flow line	18
Width of dam at top roadway	36

Dimensions of Beaver Brook Dike.	
Height of flow line above present brook	115
Height of flow line above bottom of rock gorge	250
Length of dike at flow line	2,150
Height of top of dike above flow line	18
Width of dike at top roadway	36

The upstream slopes of both dam and dike would be somewhat less steep than 1 to 3, and the downstream slopes somewhat less than 1 to 2.5.

The Reservoir Capacity.

A large part of the cost of the proposed dam and dike is due to the necessary excavation through deep layers of sand, gravel and boulders to bedrock in order to insure a watertight structure, but the material for the superstructure is easily and cheaply procured. It is evident that in the case of both the dam and the dike the upper part is much less expensive; that is, a dam at elevation 530 will not cost much more than one at a somewhat lower level, while every foot added to the height of the dam increases greatly the storage capacity of the reservoir. For instance, the upper 8 feet adds about 65,000,000,000 gallons to the storage, a quantity as great as the entire storage capacity of the Wachusett Reservoir. There is, of course, a limit above which an increase in the size of a storage reservoir is of no economic value. The increase in capacity may add little to the safe yield of the source, since the loss from evaporation may be disproportionate to the advantage gained by the larger storage. It is usually impracticable to utilize all of the water from a given source of water supply, and if the use of water is so adjusted that the supply is adequate in dry periods there will be an overflow in wet years which is apparently wasteful. Yet if the operation of the system were so arranged that no water would be wasted from it in wet years, there would be a shortage in dry years. The proposed reservoir in the Swift River valley, with a drainage area of 186 square miles and a storage capacity of 410,000,000,000 gallons, would be open to the criticism that it was disproportionately large to the size of its drainage area were it not for the fact that the plan contemplates the storage in this reservoir not only of the water of the Swift River, but also that from large areas in the watersheds of the Ware and Millers rivers in the earlier years, together with a possible subsequent extension to the Deerfield River and the addition of other areas as future circumstances may require. It will be practicable to build the dams to a lower elevation and carry them to the full height at a later time if deemed desirable, but the saving in cost would not be great, and the plans have consequently included provision for carrying the dams to the full height in the beginning.

Dimensions of Storage Reservoir.

Area of water surface (square miles)	39
Area of watershed, Swift River (square miles)	186
Area of watershed divertible from Ware River (square miles)	130
Area of watershed divertible from Millers River (square miles)	220[1]
Total capacity (gallons)	410,000,000,000
Length (miles)	17

[1] This area includes certain small watersheds from which the supplies of Ashburnham, Gardner, Winchendon and Athol are taken.

Maximum width (miles)	4
Total length of shore line not including islands (miles)	86
Maximum depth (feet)	150
Average depth (feet)	51
Length of railroad flooded (miles)	15.9
Length of highways flooded (miles)	106

Character and Occupation of Lands necessary for the Proposed Reservoir.

The reservoir would contain a number of semi-mountainous islands, rocky and, for the most part, covered with forest at the present time.

It will be necessary, for the protection of the purity of the water of the reservoir, to acquire all of the islands and lands about the margin in order to keep them free from population and from uses which might be objectionable in the neighborhood of a reservoir used for water supply purposes.

In the construction of this reservoir it is unfortunately necessary to remove several villages and practically the entire population of three of the towns in this region. The six towns most seriously affected, with their populations since 1880, together with the estimated population affected in other towns in the neighborhood, are shown in the following table: —

Town.	1880.	1890.	1900.	1910.	1920.	Estimated Population in 1920.	
						Within Proposed Swift River Reservoir.	Within Area of All Probable Takings.
Enfield	1,043	952	1,036	874	790	694	790
Dana	736	700	790	736	599	331	378
New Salem	869	856	807	639	512	60	83
Pelham	614	486	462	467	503	20	36
Greenwich	633	526	491	452	399	393	399
Prescott	460	376	380	320	236	63	236
Hardwick[1]	–	–	–	–	–	30	65
Belchertown[1]	–	–	–	–	–	4	26
Shutesbury[1]	–	–	–	–	–	3	17
Petersham[1]	–	–	–	–	–	7	10
Ware[1]	–	–	–	–	–	0	8
Totals	4,355	3,896	3,966	3,488	3,039	1,605	2,048

[1] Population of these towns very slightly affected.

The foregoing table indicates that 1,605 people, or an average of about 41 persons per square mile, will eventually have to be removed from their homes if the reservoir is constructed, and a total of somewhat over 2,000 persons including the areas likely to be required for the protection of the reservoir.

The estimated number of inhabitants on land acquired for the Wachusett Reservoir was 1,711, or an average of about 264 persons per square mile.

The assessed value of real estate in the six towns most seriously affected in the years 1901, 1914 and 1920 is shown in the following table: —

Town.	1901.	1914.	1920.
Enfield	$414,890	$470,680	$472,440
Dana	248,957	344,441	413,395
New Salem	246,760	328,600	409,910
Pelham	164,799	338,903	431,165
Greenwich	175,915	210,500	295,345
Prescott	139,012	171,322	176,905
Totals	$1,390,333	$1,864,446	$2,199,160

A careful examination of the area to be flowed shows that it contains in all 1,040 buildings besides 18 abandoned and 66 in ruins or with their foundations only in evidence. The character of these buildings is shown in the following table: —

Mill structures	14	Houses, occupied	463
Stores in use	38	Houses, vacant	30
Churches	6	Barns, in use	381
Schoolhouses	13	Barns, vacant	18
Other public buildings	2	Camps and summer cottages	61
Railroad stations, freight houses, etc.	14	Total	1,040

The total number of occupied dwelling houses as shown by the above table is 463, or about 12 per square mile, as compared with 224, or about 35 per square mile, on the area taken for the Wachusett Reservoir.

A careful survey has also been made to determine the character of the areas to be flooded and the present uses of the land. These statistics are shown in the following table: —

	Acres.
Orchards	51
Pasture and open land	2,118
Swamp and meadow	2,338
Scrub and young growth	7,889
Timber land	6,845
Water surfaces	1,233
Cemeteries	11
Unclassified lands such as village and cultivated land, highways and railroads	4,385
Total	24,870

Treatment of the Reservoir Area.

The greater part of the bottom of the proposed reservoir is composed of sandy plains covered with brush or wood and having a very thin surface layer of loam. Swamps containing peat are exceedingly rare, the aggregate area of such deposits amounting apparently to less than 700 acres. A large part of the swamp and meadow lands is low ground between the main stream and the uplands, kept in a swampy condition in many cases by the ground water from the gravelly lands adjacent. The preparation of this great area for reservoir purposes by the removal not only of all vegetation but of all surface soil besides would be impracticable on account of the excessive cost and is unnecessary in the existing circumstances. The land should be cleared of bushes and trees and all organic matter destroyed so far as practicable. It is probable, moreover, that over large areas even the surface soil can largely be reduced to ashes, so that by this process the small amount of organic matter that remains is likely to have little permanent effect upon the quality of the water of this great basin. In the earlier years, after the area is first flowed, the water will doubtless have a noticeable color, and a considerable quantity of organic matter will be taken up by contact with the material in the bottom of the reservoir, but this condition is unlikely to affect the water materially beyond the first few years. It will take several years to fill the reservoir, and during much of that time there is no doubt that water of such quality can be obtained from it that after subsequent storage in Wachusett Reservoir the quality of the water of the latter source would not be materially affected thereby, since the water need be drawn in the earlier years from the Swift River Reservoir only at times when the quality is at its best. The storage capacity of the proposed reservoir is such, in proportion to the size of its watershed, that the water stored there will eventually become thoroughly bleached and probably nearly or quite colorless, and while it may be affected at times in the earlier years by growths of organisms and the objectionable tastes and odors which result therefrom, the use of the reservoir at such times can be avoided.

With the increasing demand for water of the best quality, it is possible that most surface waters, no matter how free from probable danger of pollution, will be filtered before delivery to consumers, and this may sooner or later be the case with water supplied from the Wachusett system, but such a demand seems unlikely to arise for many years.

If it should ever be found desirable to improve the quality of the water of the proposed Swift River Reservoir by filtration before discharging it into the Wachusett Reservoir, rather than to filter all of the water supplied from the latter source, it would be practicable to filter it on lands in Oakdale adjacent to Wachusett Reservoir. But it is not probable that the water of the proposed Swift River Reservoir would differ materially from that of the Wachusett Reservoir after the first few years.

Tunnel from Swift River to Wachusett Reservoir.

The divide between the Wachusett Reservoir and the watersheds of the Ware and other rivers to the west rises to a height of over 1,000 feet above sea level, a height which it maintains generally for many miles from the northerly nearly to the southerly boundary of the State. This high divide must be pierced by a tunnel in order to bring water from the Ware or Swift rivers into the Wachusett Reservoir, and this connecting link between the present and the proposed supplies will be a most important item of construction.

The tunnel as designed will leave the Swift River Reservoir about one-half mile south of East Pond at the foot of a steep, rocky hill rising some 400 feet above the floor of the Swift River valley east of the village of Greenwich, and will run northeasterly to the neighborhood of Coldbrook in the Ware

River valley, whence it will turn to the east and follow an easterly course to the Wachusett Reservoir.

The tunnel from the Swift River valley to the Wachusett Reservoir will pass so close to Coldbrook on the Ware River that the slight change in alignment made necessary to provide for the diversion of the water of this river directly into one of the tunnel shafts would have very little effect on the length of the line. Since the control works would be located at the Wachusett end of the tunnel, the tunnel itself would become in effect a part of the reservoir, and floods from the Ware River would flow back through the tunnel and be stored in the Swift River Reservoir whenever necessary.

As previously stated, it would be possible, whenever desirable, to divert the flood flows from several small watersheds, having an aggregate area of 19 square miles or more, tributary to the Ware River below Coldbrook into the tunnel at various shaft heads. These connections are not included in the preliminary estimates, however, because the expense of their construction would probably not be justified for many years.

The total length of the proposed tunnel to the Swift River Reservoir is about 25.1 miles. It would be located in rock, and the surface indications are favorable to construction by methods known and tried in many similar cases, but as many of the construction shafts must be deep, it is desirable, for the sake of economy, that they should be spaced at intervals of 3 or 4 miles, and probably at least four years will be required for actual construction to get the first water from the Ware River at Coldbrook into the Wachusett Reservoir. Delay in beginning the construction of this tunnel, which would require more rapid work, would mean a serious addition to the cost.

The cost of such a tunnel and the time required for its construction make it advisable to build it large enough to carry as large a quantity of water as can probably be utilized from the Swift River Reservoir, developed as ultimately proposed, since the larger tunnel will cost less in proportion to its size than a small one. Accordingly, for the purpose of estimating the cost, this diameter has been taken at 12 feet 9 inches. With this diameter, in a series of dry years which might cause the main reservoir to be drawn down 55 feet, or to about elevation 475, there would still remain sufficient head on the tunnel to enable it to carry 500,000,000 gallons per day. The lowest gate sill in the intake gatehouse has been designed at elevation 435, which is about the floor of the main portion of the Swift River valley. This will allow an initial supply to be obtained the first year that the storage of water is begun, and would make it practicable to draw nearly the maximum storage of the proposed Swift River into the Wachusett Reservoir. At its lower end the invert of the tunnel as proposed would be at grade 370, the outlet of the tunnel being at Oakdale at the upper end of the Wachusett Reservoir.

Aqueduct for Millers River Diversion.

Reference has already been made to the proposed diversion of water from the Millers River into the Wachusett Reservoir through a tunnel and aqueduct leading to Eagleville Pond, and thence in a channel through the Swift River divide from the southerly end of that pond into the Swift River Reservoir. For the purposes of this estimate the aqueduct is designed at about 11.5 feet in diameter, and would be capable of diverting flows in excess of the normal undiverted flow of the river up to and including 5 cubic feet per second per square mile. The watershed of the Millers River above the proposed point of diversion is, as already stated, 201 square miles, but the flow would be reduced slightly by the diversion of water for the water supplies of Ashburnham and Athol, and by the removal of the effluent from the sewage disposal works in Gardner and Templeton, as well as those which may be built in Winchendon. The amount of these diversions from the higher flows of the river is small.

Estimates of Cost.

In making estimates of the cost of the proposed works difficulty was encountered on account of the constant changes in the prices of labor and commodities in recent years. It was decided to base the estimates wholly upon pre-war prices, and this plan has been followed throughout. The following table shows also an estimate of the probable cost of the works on a pre-war basis plus an addition of 30 per cent to allow for conditions which may exist if the bulk of these works should be constructed within the next ten to fifteen years. In making the estimates experience in similar construction on the metropolitan water supply in recent years, on similar work now under construction for the city of Providence, and especially on the water supply of the city of New York, has been utilized, as well as that of other cities. In every construction item an allowance of about 22 per cent has been made for unforeseen contingencies, all preliminary surveys and designs and the preparation of contracts, as well as administration, general supervision and engineering during construction.

Summary of Cost Estimates.

		Construction Cost and Overhead (Pre-war Basis).	Probable Cost in 1924–35 (Pre-war Basis +30 Per Cent).
Main dam at West Ware station:			
Main embankment	$7,124,000		
Diversion tunnel and control works	1,201,900		
Spillway and flood channel	251,700		
		$8,577,600	$11,150,880
Beaver Brook dike:			
Main embankment	$6,529,000		
West dike	85,000		
		6,614,000	8,598,200
Main storage reservoir in Swift valley:			
Clearing, grubbing and fencing			
Relocation and reconstruction of highways, 47 miles			
Relocation of railroad, 21½ miles		5,064,300	6,583,590
Relocation of cemeteries			
Relocation of transmission lines			
Sanitation and forestry			
Eagleville Reservoir diversion:			
Raising Eagleville dam	$44,700		
New channel via Hacker Pond	108,400		
		153,100	199,030
Millers River diversion:			
Diversion dam and intake	$159,400		
Aqueduct to Eagleville Reservoir	1,173,500		
Gardner and Winchendon sewer	729,400		
		2,062,300	2,680,990
Aqueduct to Wachusett Reservoir:			
Tunnel and shafts	$17,457,100		
Intakes to aqueduct	376,000		
Wachusett terminal	339,400		
		18,172,500	23,624,250
Total construction		$40,643,800	$52,836,940
Real estate, rights of way, depreciation, business damages, diversion damages and water rights of mills and factories below the points of diversion		....	7,109,600
			$59,946,540

THE COMMONWEALTH OF MASSACHUSETTS

PLAN AND PROFILE OF TUNNEL TO SWIFT AND WARE RIVERS

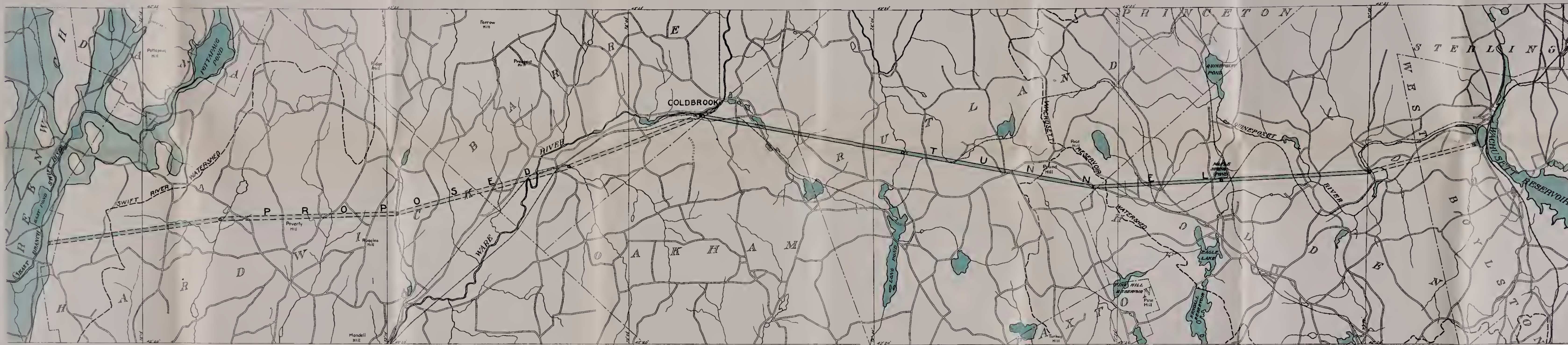
— SHOWING —

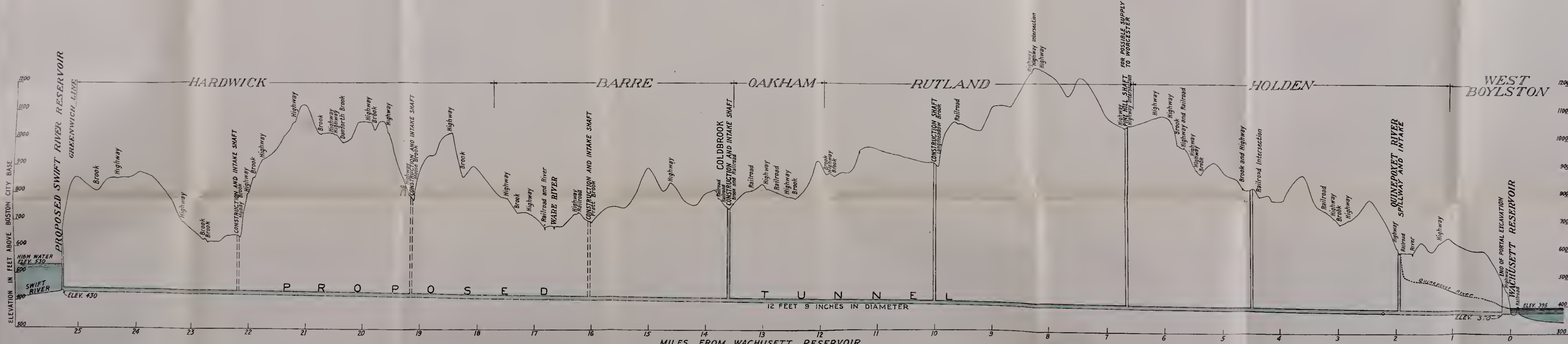
PROPOSED STAGES IN THE CONSTRUCTION

PREPARED UNDER DIRECTION OF THE JOINT BOARD
CONSISTING OF THE
DEPARTMENT OF PUBLIC HEALTH AND THE METROPOLITAN DISTRICT COMMISSION
(Chapter 49, Resolves of 1919)

JAN. 1922

SCALE





Estimated Cost of Proposed Extension to the Ware River.

The first addition to the metropolitan water supply under the plan herein proposed, which will give an additional safe yield of about 33,000,000 gallons a day, is the taking of the flow of the Ware River at Coldbrook in excess of 1.2 cubic feet per second per square mile of watershed. This involves the construction of the proposed tunnel from a shaft at the Quinepoxet River, a tributary of the Wachusett Reservoir, as far as a shaft at the Ware River in Coldbrook, including an intake reservoir and other appurtenances at Coldbrook and the necessary terminal works and diversion spillway at the Quinepoxet shaft near the Wachusett end.

The estimated cost of this portion of the works is as follows. This estimate does not include the simultaneous cost of any preliminary work on the further extension to the Swift River Reservoir, although this extension would need to be begun before the tunnel to the Ware is completed.

Summary of Cost Estimates.

First Extension to the Ware River at Coldbrook.

	Construction Cost and Overhead (Pre-war Basis).	Probable Cost in 1924–27 (Pre-war Basis +30 Per Cent).
Tunnel and shafts	$8,368,600	$10,879,180
Intakes to aqueduct	297,000	386,100
Total construction	$8,665,600	$11,265,280
Real estate, rights of way, diversion damages and water rights, mills and factories below the point of diversion	. . . .	778,100
		$12,043,380

Opportunities for Power Development.

At the main dam in the Swift River valley there will be a fall of about 141 feet in discharging the continuous flow that must be allowed to waste down the river up to the limit of 1.2 cubic feet per second per square mile. This head can be used for the production of power. A substantial gatehouse and control works must be provided in any case for the handling of these waters and their discharge down the stream, and a comparatively small additional expense will allow the installation of a water wheel and generator, and the cost of such a first installation has been included in the estimate.

At the Wachusett terminal of the tunnel, although there will be, of course, no head available for power in critical dry years in the remote future, when the full capacity of the tunnel is needed in order to supply sufficient water to the district, nevertheless, there will be a head of about 125 feet available, as soon as the Swift River Reservoir is full, which can be used for power. In later years, while more and more of the head in the tunnel will be consumed in friction and less and less will be available for power purposes, nevertheless, by opening the gates wide on nights, Sundays and holidays to pass the bulk of the water needed as the consumption increases, valuable power can be developed in 2 shifts for thirty or forty years or more to come without decreasing the head below 80 to 85 feet. The proposed diversion of the Ware River floods into the Swift River Reservoir through a tunnel construction shaft at Coldbrook is a decided benefit to the head available for power.

In addition to the above, the head at the Wachusett terminal could be still further increased and a very considerable present waste of water power conserved by intercepting the Quinepoxet River, one of the main tributaries of the Wachusett Reservoir, at a point about 155 feet above its present outlet, and diverting it into one of the construction shafts of the tunnel. Thus the Quinepoxet River, instead of discharging down the steep, barren channel which was stripped of its power plants when the Wachusett Reservoir was built, can be diverted at a very small additional cost into the tunnel and used for power.

Furthermore, the additional water required for the district will increase the power available at the Wachusett dam at Clinton. The present power plant at that point has a capacity equal to that of the Wachusett Aqueduct, hence no new units would be required in order to take advantage of the new supply from the proposed Swift River Reservoir.

The use of the Swift River water would also add to the available power at the Sudbury dam, but before very many years, in case it is desired to take full advantage of the power possibilities in connection with the new supply, extensive alterations would be required at this plant, since the structure which contains the present Sudbury power plant was originally a gatehouse and was not intended as a power station. It will not pay to make alterations until some future time when the draft on the new supply is materially increased. Hence, the cost of such changes has not been included in the estimates of cost of the proposed works.

CONCLUSIONS — METROPOLITAN DISTRICT SUPPLY.

Financial Statement.

The greater part of the works required for an additional water supply for the Metropolitan District under the plan herein recommended will be adequate for a very long period in the future, and this consideration should be taken into account in the payment of indebtedness created for the construction of the works. The serial bond method of financing the cost of public works with equal or nearly equal payments on principal over a stated period is generally advantageous as a method of meeting the indebtedness for public improvements, and in most cases insures payment for the bulk of the works during the period of their greatest use. But in the case of a large water supply project such as here proposed, which requires a long period for construction and the use of which will increase as time goes on, such a method of financing would involve a large expense for payments on indebtedness, even before the bulk of the works could be completed, and long before they would come into full use.

The present water supply system of the Metropolitan Water District was financed under the sinking fund method, and with the able manner in which these funds have been handled the plan has proved in all respects a most satisfactory one. The annual cost of payments on indebtedness for the $40,000,000 debt created gradually increased to a maximum of about $1,950,000 in 1912. Since 1905, however, with the growth in population, the per capita cost has gradually decreased, as shown in the following table: —

Per Capita Cost of the Metropolitan Water Debt.

Year.	Per Capita Cost of Payments on Account of Outstanding Debts.	Year.	Per Capita Cost of Payments on Account of Outstanding Debts.
1898	$0 44	1910	$1 89
1899	62	1911	1 85
1900	86	1912	1 82
1901	1 35	1913	1 77
1902	1 45	1914	1 53
1903	1 80	1915	1 51
1904	1 96	1916	1 50
1905	2 06	1917	1 49
1906	2 01	1918	1 49
1907	1 92	1919	1 50
1908	2 02	1920	1 47
1909	1 93		

The cost of interest and sinking fund taken together would now be less and in the future would probable continue to grow less, up to the time the bonds are paid, if the payments had been larger in the earlier years. But, on the other hand, such excessive amounts as would have been required in those years under the serial bond method of payment as commonly applied would have been a serious hardship during the construction, and in this instance during the earlier years of operation, of the works. During that period the population was much smaller than it is to-day, the income of the water departments less, and the water works had not become fully available for use.

The annual cost of the present metropolitan water system will probably change but little in the next fourteen years except for a gradual increase in the cost of maintenance, while the total cost per capita will gradually decrease. In the year 1935 nearly one-third of the bonds issued for the construction of the works will become due, and the cost for capital charges will then rapidly diminish for the next seven or eight years, when the bulk of the entire indebtedness will be paid. Under these conditions, in financing the proposed new works, the construction of which cannot be completed in any case before 1936, even if begun at once, it would be a great advantage if the payments on capital charges were made small in the beginning and were to increase materially when payments on the original debt begin to reduce rapidly the charge on that account in 1936.

The income of the water departments in the various cities and towns in the district is a constantly increasing one, and in many cases a considerable part of the receipts for water is used for other purposes. The extent to which the receipts may be expected to increase is such that by a reasonable arrangement of payments, whether by serial bonds or other method, little increase if any is likely to be required in the amounts to be charged for water, and then only in the period previous to the beginning of the retirement of the present metropolitan bond issue in 1935.

A review of the financial conditions on which this conclusion is based will be found in an appended statement which shows that the per capita cost of operation of water works in the communities in the Metropolitan Water District is less in practically all cases, except where, owing to summer residents, the population using the water is greater than indicated in the census returns, than in the cities and towns outside the Metropolitan Water District, a condition which would naturally be expected when the cost of operation of one large works is contrasted with that of many smaller ones, even though the distributing systems in the Metropolitan Water District are separately and independently operated.

Time required for Construction and Urgency of Preliminary Work.

The first addition to the works recommended herein is the construction of the proposed tunnel to the Ware River at Coldbrook. Assuming that no unusual difficulties are encountered, and that the work is carried on to the best advantage, it will require with the necessary preliminary work about six years to complete the tunnel to this point after the work is authorized by the Legislature. The time required for the completion of the whole works from the beginning will be about fourteen years. During the latter two years of this period water can be stored in the Swift River Reservoir, so that an additional supply from the Swift River will be available for use after the end of the twelfth year. This conclusion is based on the assumption that the work will be carried on energetically from the beginning, and that no extraordinary difficulties or delays will be encountered.

It will be feasible to vary the schedule of construction to a limited extent to meet unusual or unexpected circumstances affecting the growth of population or the use of water within the next few years, but if the plan is adopted it is essential that the preliminary work shall be begun at the earliest possible time, since this work is necessary before any construction can be undertaken.

Of especial importance is the establishment of measuring stations to record accurately the river flow at all times, especially in the watersheds of the Ware, Swift and Millers rivers. Such records should be made available to all who may be interested in the use of the water of these rivers, whether for water supply or any other purpose. The measuring stations already established and long maintained in these valleys should be continued and such others established as are necessary in connection with the proposed future use of these rivers in part for water supply purposes. At the same time, the stations established in connection with this investigation for the accurate measurement of rainfall in these watersheds should be continued and supplemented so far as may be necessary to determine with reasonable accuracy the precipitation upon which the flow of the streams depends.

It is important, both to insure the quality of the water and to provide against possible droughts, that a large storage be secured as soon as possible after the supply is first made available. This requires the completion of the reservoir on the Swift River in advance of large consumption needs, in order that it may fill rapidly while the necessary drafts therefrom are comparatively small.

Too much emphasis cannot be placed upon the fact that any adequate extension of the metropolitan water supply must be inevitably of great magnitude, and must require many years for proper preparation and completion.

It is needless to say that a comparatively small extra cost resulting from the early completion of the water works would be of little consequence compared with the losses from a general shortage of water. Furthermore, the extra cost due to need for haste in construction might be very considerable in case the beginning of construction is delayed.

Where the public health, comfort and safety are so vitally concerned, especially in a district which comprises nearly half the population of the State, it is most essential to make such provision for the needs of the district as will prevent danger of shortage of water at any time.

General Summary.

The consumption of water in the Metropolitan Water District at the present time practically equals the amount of good water obtainable in dry years from Wachusett Reservoir, Sudbury Reservoir and Framingham Reservoir No. 3. This fact has not been as apparent as it otherwise might be because of the excessive rainfall in the past few years, as a result of which, especially in 1920, considerable quantities of water were necessarily wasted from these reservoirs.

In view of the impending shortage, preparation should be made for filtering the water from the southern Sudbury and Cochituate sources in season to prevent any excessive lowering of the storage in the Wachusett system.

All the existing sources together are likely to be inadequate for the district alone, at the expected rate of growth, by 1928 or 1930. Should the requirement be increased by the addition of other municipalities or by the increase in the use of water by the municipalities now entitled to take water from the district sources, the time during which these sources would be adequate would be shortened by an amount depending considerably upon the uncertain quantity of the rainfall from year to year.

There is no doubt that an additional water supply should be obtained for the district as early as possible, and the results of the investigation show clearly that the most appropriate method of enlargement would be to take flood waters from the Ware River. At the same time, the initial steps should be taken in a plan for adding a much larger quantity of water by the construction of a reservoir on the Swift River which would make available the flood flows of that stream as well as those of the Millers River.

The essential feature of the plan herein presented is the taking and storing in an adequate reservoir of the water of the freshets and of the higher flows of several rivers for water supply uses, thus avoiding diversions of water from any of these watersheds at times when the flow is materially below the average. Every year millions of gallons of water run to waste down these rivers, useless for any practical purpose and sometimes in quantities to cause damage to or interference with industries in the mills and villages below. It is the flood waters and the higher flows that it is proposed to divert for water supply when the flow is more than 1.2 cubic feet per second per square mile, or a little less than 800,000 gallons per day per square mile. The flows below that amount will be allowed to continue to run in the rivers at all times, except in the case of the Swift River, where they can be stored if desired and be discharged to the best advantage of those using the water along the river below.

Another essential feature of this plan is that it lends itself in a remarkable degree to gradual development step by step, and involves no expenditure for temporary or makeshift construction. It thus allows the details of the construction to be modified by circumstances and requirements which may appear from time to time. Beginning with the diversion of the upper portion of the Ware River watershed, the plan not only provides for extension to the Swift River, but looks ahead ultimately to a longer future and to a very much larger supply by diversions from other watersheds into the proposed Swift River Reservoir, following the same principle of utilizing only the higher flows, for the most part in excess of the requirements of present users. Such a policy of preparation for the future is essential in case of this most important public utility.

This plan develops the higher flows of the Ware, Swift and Millers rivers, and the large reservoir in the valley of the

Swift River provides a sufficient storage of water to meet the needs of the Metropolitan Water District for a very long time in the future. The greater part of the completed works will be useful for an indefinite period, and will provide insurance against drought as severe as any that has been experienced in the last one hundred years. Furthermore, enough water will be available to provide not only for an enlarged district, but also for near-by municipalities, and even manufacturing centers far away, such as Worcester, whose supplies are either limited in quantity or are of poor quality for water supply purposes. In other words, it will give many municipalities an opportunity to join in a larger plan to their own advantage as well as that of the district itself.

The new supply insures for the future the present high standard of quality to which the people of the district have become accustomed, and allows a continuation of the varied uses to which the public waters are applied. The water obtainable under this plan will be drawn from watersheds even more sparsely populated than was the Wachusett when works for taking water from that watershed were planned. The only population of importance is found in two or three towns in the watershed of the Millers River and there is no question but that this can be dealt with satisfactorily. The water from all of the sources is clear and soft, and, while some of the waters contain considerable color, in no case is the color excessive, and it will practically disappear after storage in the proposed reservoir. The site of the proposed Swift River Reservoir is most favorable in that it contains no swamps of consequence, and the gravel and sand with which the valley bottom is filled is covered with comparatively little surface soil. It is unnecessary, under the circumstances, to remove the soil from this great area as was done in the case of the Wachusett Reservoir.

Finally, the proposed sources of supply will yield ample quantities of water without further expenditure for construction during the life of long-term bonds. In other words, the expense can be distributed over a long period of years during which time no important new construction will be required until the debt can be wholly liquidated.

WATER SUPPLY OF SOUTHEASTERN MASSACHUSETTS.

Southeastern Massachusetts, as designated in this report, includes the counties of Bristol, Plymouth, Barnstable, Dukes and Nantucket. The population of each in 1920 as shown by census records, with its area and population per square mile, is as follows: —

	Population, 1920.	Area (Square Miles).	Population per Square Mile.
Bristol	359,005	554.4	648
Plymouth	156,968	663.0	237
Barnstable	26,670	394.1	68
Dukes	4,372	105.8	41
Nantucket	2,797	49.5	57
Totals and average	549,812	1,766.8	311

In the three counties of Barnstable, Dukes and Nantucket there are no cities or large towns, and water supplies of excellent quality, adequate for all purposes, are readily available to the municipalities in that part of the State.

Water Supplies of Plymouth County.

There are several municipalities in Plymouth County of importance in this connection which deserve special mention, among which is the city of Brockton which had a population in 1920 of 66,254. This city supplies water to several of the surrounding towns from Silver Lake, located in Kingston, Pembroke, Halifax and Plympton, and also retains for emergencies a storage reservoir on Salisbury Brook in Avon, from which the water supply of the city was formerly drawn. Practically all services are metered, and the average daily consumption of water in 1920 was 2,931,000 gallons, equivalent to 44 gallons per capita per day.

Silver Lake furnishes water of good quality, soft and practically colorless, and the quantity which it is capable of supplying is adequate for all present requirements of the city of

Brockton and the other communities supplied from this source. Its yield can be materially increased by diverting into it by gravity the flow of two streams, Howard and Pine brooks, which drain sparsely settled watersheds in the neighborhood of the lake. There are also other sources in this region which may be used if necessary in the future. There appears to be no necessity at the present time of providing further sources of water supply for this city nor for the group of communities dependent upon it for their water supplies.

Next to Brockton the town of Plymouth is the largest municipality in Plymouth County, with a population in 1920 of 13,045. The water supply in this town is taken from Great South and Little South ponds, which have thus far been sufficient for all requirements. There are numerous other ponds in the town many of which contain water of good quality from which a further supply can be obtained when required.

The towns of Abington and Rockland, having an aggregate population in 1920 of 13,331, obtain a joint supply from Great Sandy Bottom Pond in Pembroke. The water is soft, nearly colorless and naturally of good quality for water supply purposes, but the purity of this supply is menaced by the numerous cottages about the shores of the pond and within its watershed. Either the cottages about the pond and other possible sources of pollution should be removed from the watershed, and adequate protection of the water supply secured, or the water should be filtered. This water supply can be supplemented from other sources in the neighborhood when an additional supply is required.

Water Supplies of Bristol County.

The county of Bristol is fifth in number of inhabitants in the State and fourth in density of population, the population per square mile being exceeded only by Suffolk, Middlesex and Essex counties. Five-sixths of the population is concentrated in the cities of New Bedford, Fall River, Taunton and Attleboro, and most of the remaining municipalities of considerable population are adjacent to these cities.

The city of Attleboro, population in 1920, 19,731, obtains its water supply from reservoir and ground-water sources in the watershed of the Seven Mile River, and the consumption of water in the city has reached the safe yield of these sources of supply. There are other waters in the region about the city, however, from which an additional supply can be obtained independently, and probably without special difficulty, so that in the light of present information it will be best probably for Attleboro to continue as at present to obtain a water supply from independent sources in the neighborhood of the city.

The chief problems of water supply in southeastern Massachusetts are found, however, in Bristol County, and are especially those of the large and growing manufacturing cities of New Bedford, Fall River and Taunton in the central and southerly part of that county.

Present Sources of Supply, Population and Consumption of Water in New Bedford, Fall River, Taunton and Near-by Towns.

The city of Fall River obtains its water supply at present from North Watuppa Pond, and the cities of Taunton and New Bedford, including the towns of Acushnet and Dartmouth, which are furnished with water by the city of New Bedford, take their supplies from the Lakeville Ponds. The population of the cities of New Bedford, Fall River and Taunton, including that of the towns of Dartmouth and Acushnet, now supplied with water by the city of New Bedford, has increased from 144,728 in 1890 to 288,407 in 1920; that is, the population has doubled in thirty years. The aggregate quantity of water used in these municipalities in 1890 was about 7,000,000 gallons per day, while in 1920 it was about 19,950,000 gallons. The growth of these cities in the future will be affected doubtless by varying business conditions, changes in industries and other causes, and these causes will also affect the quantity of water which will be used from the public supply. The per capita consumption of water is gradually increasing here as elsewhere after the meter system has become established, and in making provision for future water supply requirements allowance must be made for further gradual increase in the per capita consumption of water. Assuming that these cities will continue to increase in population in the future about as in the past, and allowing for a gradual increase in the consumption of water per capita, the probable future water supply requirements have been estimated as shown in the table which follows.

Included in this table is an estimate of the probable future growth and water supply requirements of a number of towns situated in the neighborhood of the three principal cities in this region or in the region about the Watuppa and Lakeville ponds, some of which are already supplied with water from these cities or have rights reserved in the ponds, while the others are included for the reason that it seems likely that they will find it most convenient at some time in the future to obtain their water supplies either directly from one or the other of these groups of ponds or from municipalities supplied therefrom. The towns included in this classification are Acushnet, Dartmouth, Middleborough, Somerset, Fairhaven, Freetown, Raynham, Westport and Lakeville.

Population and Water Consumption of New Bedford, Fall River, Taunton, and Various Small Towns.

	1920.[1] Population.	1920. Per Capita Consumption (Gallons).	1920. Total Consumption (1,000 Gallons).	1925. Population.	1925. Per Capita Consumption (Gallons).	1925. Total Consumption (1,000 Gallons).	1930. Population.	1930. Per Capita Consumption (Gallons).	1930. Total Consumption (1,000 Gallons).
New Bedford	121,217	83.2	10,085	136,300	87.0	11,858	151,700	90.6	13,744
Fall River	120,485	52.9	6,374	132,800	56.9	7,556	144,500	60.6	8,757
Taunton	37,137	91.4	3,394	40,000	93.9	3,756	42,900	96.4	4,136
Totals	278,839	71.3	19,853	309,100	75.0	23,170	339,100	78.6	26,637
Various small towns.	36,593	45.0	1,647	40,600	47.5	1,929	44,700	50.0	2,235
Totals	315,432	68.2	21,500	349,700	71.8	25,099	383,800	75.3	28,872

	1935. Population.	1935. Per Capita Consumption (Gallons).	1935. Total Consumption (1,000 Gallons).	1940. Population.	1940. Per Capita Consumption (Gallons).	1940. Total Consumption (1,000 Gallons).	1945. Population.	1945. Per Capita Consumption (Gallons).	1945. Total Consumption (1,000 Gallons).
New Bedford	166,900	94.1	15,705	181,900	97.5	17,735	196,400	100.8	19,797
Fall River	155,800	64.1	9,987	166,800	67.4	11,242	177,200	70.5	12,493
Taunton	45,800	98.9	4,530	48,700	101.4	4,938	51,600	103.9	5,361
Totals	368,500	82.1	30,222	397,400	85.4	33,915	425,200	88.5	37,651
Various small towns.	48,900	52.5	2,567	53,200	55.0	2,926	57,600	57.5	3,312
Totals	417,400	78.6	32,789	450,600	81.8	36,841	482,800	84.9	40,963

[1] 1920 figures actual; others estimated.

Population and Water Consumption of New Bedford, Fall River, Taunton and Various Small Towns — Concluded.

	1950.			1955.			1960.			1965.			1970.		
	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).	Population.	Per Capita Consumption (Gallons).	Total Consumption (1,000 Gallons).
New Bedford	210,800	104.0	21,923	225,000	107.1	24,097	239,100	110.1	26,325	253,200	113.0	28,612	267,100	115.8	30,930
Fall River	187,500	73.4	13,763	197,200	76.1	15,007	206,800	78.6	16,254	215,800	80.9	17,458	224,800	83.0	18,658
Taunton	54,400	106.4	5,788	57,200	108.9	6,229	60,000	111.4	6,684	62,800	113.9	7,153	65,600	116.4	7,636
Totals	452,700	91.6	41,474	479,400	94.6	45,333	505,900	97.4	49,263	531,800	100.3	53,223	557,500	102.7	57,224
Various small towns	62,000	60.0	3,720	66,500	62.5	4,156	71,000	65.0	4,615	75,500	67.5	5,096	80,000	70.0	5,600
Totals	514,700	87.8	45,194	545,900	90.7	49,489	576,900	93.4	53,878	607,300	96.1	58,319	637,500	98.7	62,824

Available Sources of Water Supply in Southeastern Massachusetts.

In general this part of the State is a most unfavorable one in which to obtain water in large quantities which is of satisfactory natural quality for municipal water supply uses. The watershed of the Taunton River, which drains the greater part of Bristol County, and those of the small coastal streams lying between this watershed and the sea to the south and east are mostly quite flat with wide, shallow valleys, offering, as a rule, little opportunity for the construction of storage reservoirs of considerable capacity suitable for water supply uses. The valleys, for the most part, contain extensive areas of swamps, and the largest aggregate area of swamp lands in the State is found in this region. Furthermore, many of the valleys are densely populated, and the streams which drain them are seriously polluted. In consequence of these conditions, the waters of the streams are generally highly colored and objectionable for water supply uses.

While these conditions are the rule, this region contains, nevertheless, two remarkable groups of large natural ponds comprising the largest natural reservoirs in the State — one the Lakeville Ponds, situated for the most part in Middleborough and Lakeville, and the other the Watuppa Ponds in Fall River and Westport.

Description of the Watuppa Ponds and the Water Supply of Fall River.

The North and South Watuppa ponds are situated in the city of Fall River and the town of Westport a short distance east of the thickly populated part of the city of Fall River. Though formerly connected, they are now separated by a causeway which forms a dam, and the water of the North Pond is ordinarily kept a few inches higher than that in the South Pond. Together these ponds have a total length of 8 miles, while the maximum width of the North Pond is about 1 mile and that of the South Pond $1\frac{1}{2}$ miles.

The area and capacity of each of these ponds and the original drainage area of each, now considerably modified, are shown in the following table: —

Area and Capacity of Watuppa Ponds.

Pond.	Drainage Area (Square Miles).	Area (Square Miles).	Approximate Capacity (Million Gallons).
North Watuppa	11.44	2.82	7,200
South Watuppa	16.10	2.42	8,000

The population has encroached to such an extent upon the watershed of South Watuppa Pond that it is no longer practicable to use that source for water supply even were its waters not required for other uses.

The water supply of Fall River is taken from North Watuppa Pond and was introduced about the year 1875. The water of this pond is soft, clear and low in color and naturally of good quality for water supply purposes. As the city grew, however, the population extended into the watershed, and in order to protect its water supply the city began many years ago the purchase of lands about the pond and within its watershed, and now controls about 3,295 acres of land for this purpose, or about 60 per cent of the total area of the watershed of North Watuppa Pond. It was found to be impracticable, however, to secure control of the lands in the thickly populated areas adjacent to the city, or of certain areas in Westport on the easterly side of the pond, which had also become thickly populated, and in order to protect the water supply adequately it was found necessary to divert the flow of water from these areas through intercepting drains into the South Pond. The intercepting drain along the westerly shore of North Pond has been constructed and is now in operation, and plans for the intercepting works on the easterly side of the pond have been completed, but the work was interrupted by the war.

These diversions are as follows: —

West Shore Intercepting Drain (now in Operation).

	Square Miles	
Cress Brook	.47	
Highland Brook	1.08	
Terry Brook	.22	
Area in County Street	.55	
Total		2.32

Ralph and Nat Brooks, Proposed Diversions.

	Square Miles.	
North Nat Brook	.21	
South Nat Brook	.16	
Part of Ralph Brook	.21	
Total		.58
Total North Pond diversions		2.90

The effect of these changes upon the drainage area of North Watuppa Pond is as follows: —

	Square Miles.
Original drainage area:	
Land surface	8.62
Water surface	2.82
Total	11.44
Area after present and proposed diversions:	
Land surface	5.72
Water surface	2.82
Total	8.54

The drainage area of the South Pond has been augmented correspondingly by these diversions.

The safe yield of the North Pond depends to a considerable extent upon the amount of storage utilized in dry years. The Watuppa Reservoir Company owns the flowage rights in North Watuppa Pond, though the city of Fall River has the unlimited use of the water for domestic purposes, and negotiations are pending for the control by the city of the flowage rights in the pond.

North Watuppa Pond, in dry periods, will provide a safe yield of about 7,000,000 gallons per day by drawing down the level of the pond about 5 feet. An additional amount can be obtained by further depletion of the storage, but it is desirable to retain a large amount of water in the pond for the purification and protection from pollution which storage affords. The quantity of water which this source is now capable of yielding with the pond drawn to a depth of about 5 feet is approximately 10 per cent in excess of the consumption of water in the year 1920, and is liable to be exceeded at any time; that is, the city of Fall River in that year was using nearly as much water as its source of supply will yield in a dry period, and an additional supply must be obtained for use in the immediate future.

The water of North Watuppa Pond is naturally of excellent quality for domestic use, being soft and low in color, while the quantity of organic matter which it contains is usually small. The quality deteriorated considerably in the earlier years of the use of the pond up to the time of the completion of the intercepting drain in 1916. For nearly thirty years preceding that time the quantity of organic and mineral matter gradually increased. Since 1916 there has been an improvement, and the mineral and organic contents of the water have materially diminished.

Investigations for Additional Supply by the City of Fall River.

The Fall River authorities, well aware of the need of a further supply of water, have given the problem of additional supply thorough study within the past few years. At first sight South Watuppa Pond appears to be a readily available source, but aside from the fact that that pond is now exposed to pollution in a rapidly increasing degree by the large population on its watershed, the pond is the main source of water supply for mechanical and manufacturing uses in the city, and a large part of the yield of the pond is used for such purposes. Furthermore, the maintenance of satisfactory sanitary conditions in the Quequechan River below the pond is one of the serious problems now under consideration, and the diversion of further quantities of water from the watershed of that stream is inadvisable in any case and would be objectionable under existing conditions. Investigations for an additional water supply have included thorough studies by the engineers of the city of the practicability and cost of obtaining water from some of the watersheds east and north of North Watuppa Pond, and the more favorable of these sources have been very carefully examined, viz., Mill Brook, the watershed of which lies contiguous to that of North Watuppa Pond on the north, Copecut River, the headwaters of which lie farther to the east, and Bread and Cheese Brook, which drains an area somewhat farther to the south.

The results of these investigations indicate that the cost of works for taking water from the more favorable of these sources would be large, while the quantity of water obtainable by any of these plans would be sufficient to meet the needs of the city for only a comparatively limited number of years in the future.

The investigations of the city have also included the study of a plan for obtaining water from the Lakeville Ponds, and a comparison of the results of all the studies indicates that the last-named plan, while more expensive in the beginning, would in the long run prove to be the most desirable method of obtaining an additional water supply for Fall River.

The Water Supplies of New Bedford and Taunton from the Lakeville Ponds.

New Bedford.

The water supply of New Bedford was introduced in 1869, the source of supply at that time being a storage reservoir on the Acushnet River north of the city. In 1886, at a time of shortage of water, a connection was made between Little Quittacas Pond and the Acushnet River, and this arrangement was continued for several years. In 1894 the city was authorized to establish an additional water works near Little Quittacas Pond, and to divert water from Great Quittacas Pond through Little Quittacas for the use of the city. Works for this purpose were completed in 1899. Chapter 345 of the Acts of the year 1894, the act under which this water supply was established, contains the following provisions relative to the proposed sources of supply: —

Section 1. The city of New Bedford is authorized to establish additional water works at or near the Little Quittacus pond, and all necessary conduits and other suitable structures for distributing water to, into and through said city from Great Quittacus pond through Little Quittacus pond; and may also take and hold by purchase or otherwise all lands, rights of way and easements necessary for holding and preserving such water and for protecting the purity of the same; . . .

SECTION 3. Said city may erect a dam between Great Quittacus and the Pocksha ponds with suitable waterways for the discharge or overflow of surplus waters from Great Quittacus into Pocksha pond, but said waterways shall be so controlled by gates or otherwise as to prevent water from passing back from Pocksha to Great Quittacus pond. Said city may make such changes in any public way as are made necessary or proper by the construction of such dam, leaving such way in as good condition as before such alterations were made.

SECTION 6. Said city shall be liable to pay all damages that may be sustained by any persons in their land by any taking thereof by said city, also by any flowage damages under this act, also by any owner of water rights on or below the Nemasket river, caused by the diminution of the natural flow of the waters from Great Quittacus pond under the provisions of this act. . . .

SECTION 7. The city of Taunton shall be hereafter relieved from maintaining such proportion of the natural flow of the Nemasket river as the diminution of the natural flow of the waters from Great Quittacus pond under this act will represent.

Under legislative authority the city of New Bedford, in connection with the construction of its water works, built a dam between Great Quittacas and Pocksha ponds which prevents water from the latter overflowing into Great Quittacas except at times of high water, but allows surplus water from Great Quittacas to overflow into Pocksha when necessary. The city of New Bedford thus controls the entire yield of Great and Little Quittacas ponds. The safe yield of these sources is probably about 20 per cent greater than the quantity of water used in the city of New Bedford in 1920.

The city of New Bedford at the present time supplies water to the adjacent towns of Dartmouth, Acushnet, and a small area in Freetown, the quantity used in Dartmouth in 1920 having been 43,000 gallons per day, and in Acushnet 48,000 gallons per day. The city is also authorized to sell water to Lakeville.

The old storage reservoir on the Acushnet River has not been used regularly for many years, but is still available for emergencies. The water of this reservoir has always been high in color, however, and contains a larger amount of organic matter than is found in the waters of most of the natural ponds in this region. The reservoir has an area of about 300 acres, a storage capacity of about 400,000,000 gallons, and receives the flow from a rather sparsely populated watershed of about 5.3 square miles. Its safe yield is probably about 3,600,000 gallons per day. Its water could be used probably in an emergency provided proper sanitary inspections were maintained within the watershed, but at the present time water of this character with its excessive color would no doubt be objectionable unless filtered, and the expense of making it satisfactory for the use of the city would be large in proportion to the amount of water obtainable.

Taunton.

The water supply of Taunton is taken from Elders and Assawompsett ponds. Under present conditions water is pumped from Assawompsett Pond, at a pumping station located on its westerly shore about half a mile north of the point at which the outlet from Long Pond enters Assawompsett, to Elders Pond, whence it flows by gravity to the pumping station in Taunton through which it is supplied to the city. The works were completed in the year 1894. The legislation which authorized the city of Taunton to take water from these sources, chapter 217 of the Acts of the year 1875, contains the following provisions relating to the proposed sources of supply: —

Section 1. The city of Taunton is authorized to take and hold the waters of either Taunton river, in the city of Taunton, or in the town of Raynham, or Elders' and Assawompsett ponds in the towns of Lakeville, Middleborough and Rochester, and the waters in said towns which flow into said ponds, together with any water rights connected therewith, and may take and hold, by purchase or otherwise, such land around the margin of said ponds, not exceeding five rods in width, as may be necessary for the preservation and purity of said waters, and may also take and hold such lands as are necessary for maintaining dams and reservoirs for the storage of said waters, and for laying and maintaining conduits, pipes, drains and other works for collecting, conducting and distributing said waters through said city of Taunton: *provided, however*, that if said city of Taunton take water from said Assawompsett Pond the said city shall construct and maintain a dam at the place where the Assawompsett Pond flows into Namasket River, not exceeding two and one-half feet in height above the mud sill as it now exists at said place; and *provided, further*, that if said dam shall not retain sufficient water for one year's supply for the city of Taunton, then said city shall have the right to, and shall raise said dam to such a height as will retain sufficient water for one year's supply for said city of Taunton. It is also provided that the natural flow of said Assawompsett Pond into the Namasket River shall at all times be maintained.

The available yield of Assawompsett Pond is far in excess of the quantity of water required by the city of Taunton, since Assawompsett Pond receives also the flow of Long and Pocksha ponds, and, in fact, of the entire drainage area of the Lakeville Ponds not controlled by the city of New Bedford.

The Lakeville Ponds as Sources of Water Supply for the Joint Use of the Cities of New Bedford, Fall River, Taunton and Other Municipalities in their Vicinity.

The Lakeville Ponds have been used as sources of water supply by New Bedford and the suburban towns which that city supplies, as well as by Taunton, through works installed more than twenty years ago.

The entire group comprises five large lakes and a few smaller ones situated in Middleborough, Lakeville, Rochester and Freetown, at the headwaters of the Nemasket River, a tributary of the Taunton River, which enters that stream from the east a few miles northerly from the center of Middleborough. The ponds are shown on the accompanying map of this region which includes also North Watuppa Pond.

The principal pond in the group is Assawompsett, while the others fall naturally into two groups both tributary to Assawompsett. The waters of Elders Pond flow naturally into Long Pond and thence into Assawompsett near its southerly end, while on the easterly side the waters of Little Quittacas Pond flow naturally to Great Quittacas and thence in times of high flow to Pocksha Pond which is practically an arm of Assawompsett on its easterly side. The water from the entire chain of ponds formerly discharged into Nemasket River from the northerly side of Assawompsett Pond. The conditions of flow in these ponds have been materially changed, however, since the cities of New Bedford and Taunton began drawing water from some of them. Consequently, in very dry years under present conditions little or no water overflows from Great Quittacas into Pocksha Pond, and Elders Pond no longer flows into Long Pond. In order to determine the probable yield of the Lakeville Ponds the available information concerning them has been collected, especially the surveys already made by the cities concerned, and, so far as practicable within the limit of the available appropriation, this information has been supplemented by additional surveys to determine the capacity of the ponds, the character of their watersheds, and the extent and character of the present occupation of the lands about them. The areas of the ponds and their watersheds, together with the capacity of each so far as determined by the surveys and observations, are shown in the following table: —

Pond.	Area of Watershed, including Water Surface (Square Miles).	Area of Water Surface (Square Miles).	Storage Capacity (Million Gallons).	Elevation at which Data are taken[1] (Boston City Base).
Long Pond	21.22	2.80	5,730	61.45
Assawompsett and Pocksha ponds	13.17	4.20	8,900	60.79
Great Quittacas Pond	11.42	1.81	4,990	60.07
Little Quittacas Pond	1.39	.50	1,030	59.57
Elders Pond	.53	.22	692	93.54
Totals	47.73	9.53	21,342	–

[1] These elevations, observed on March 18, 1920, are the highest recorded during the progress of the surveys.

Safe Yield of Lakeville Ponds.

From the information secured it appears that by using the storage to its full practicable extent the total watershed tributary to this group of ponds above the outlet of Assawompsett Pond is capable of yielding in a series of dry years about 42,000,000 gallons per day. The ponds are so large in proportion to the area of their watersheds, however, that by diverting water into them from adjacent and very sparsely populated areas in the region about them a much larger supply can be secured than their own watersheds will furnish. The safe yield of their present watersheds alone, assuming that the city of

Fall River will continue to use the North Watuppa Pond to its full practicable extent, will probably be sufficient to meet the requirements of the cities and towns likely to be supplied from them for the next thirty-five years.

Swamp Areas.

The watersheds of these ponds, like most watersheds in this region, contain extensive areas of swamps, the improvement of which will be necessary to maintain and improve the quality of the water in the ponds. These swamps, which have an aggregate area of 5.34 square miles, fall naturally into two classes, the first of which includes those which are adjacent to the streams tributary to the ponds, such as the swamps adjoining Black Brook, Fall Brook at the southerly end of Long Pond, and Elders Pond Brook, which contain in the aggregate some 2,400 acres. The brooks which drain these swamps have sufficient fall, for the most part, to allow for their adequate drainage by means of suitable channels and appurtenant works. The second group includes those swamps which are adjacent to the shores of the ponds themselves. There are about 48 swamps, large and small, in this class having an aggregate area of approximately 1,016 acres and a total frontage bordering the ponds of about 41,800 feet. They occupy about 23 per cent of the shore line of the ponds and extend back from the shores for distances varying from 100 to 4,600 feet. Their surfaces lie, for the most part, little above the normal high-water surfaces of the ponds, but by drainage, diking or other means they can be either drained or so dealt with as to prevent them from affecting seriously the condition of the water in the ponds. These low-lying swamps offer separate problems which require detailed study and individual solution.

Quality of the Water.

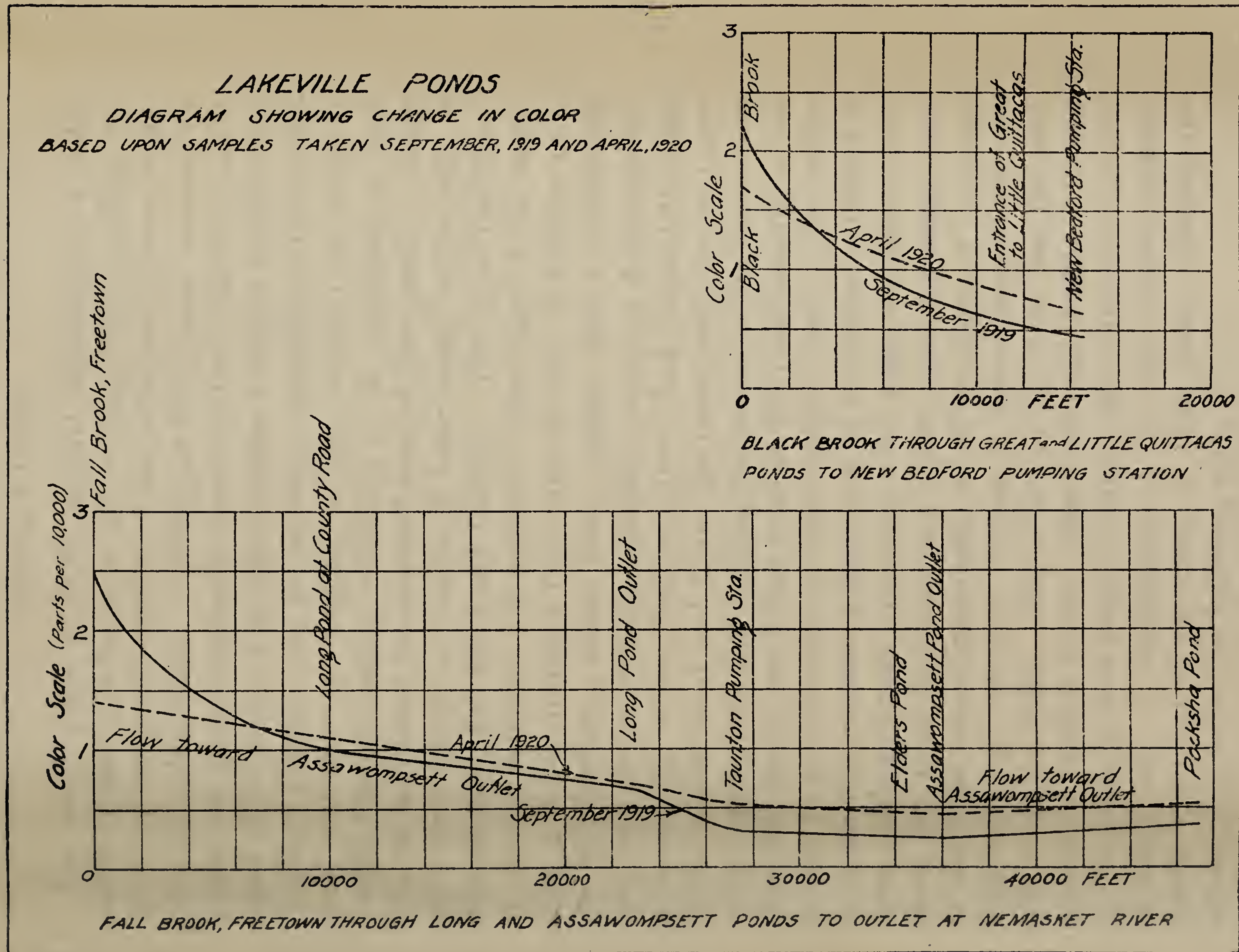
The water of all the Lakeville Ponds is very soft and naturally of excellent quality for water supply uses. The comparatively low color of the water of most of these ponds is in remarkable contrast to that of their chief tributaries, among which are some of the most highly colored waters in the State.

The change in color as the water passes from the tributaries to the outlets of the ponds is well illustrated in the following diagram, which shows the changes in color from Fall Brook through Long Pond and Assawompsett Pond to its outlet and also to Elders Pond, and the change in color from Black Brook through Great and Little Quittacas ponds to the New Bedford pumping station whence the water is drawn for the supply of that city.

Color and its Elimination.

The high color of the waters of the tributaries of these ponds is due to the slow passage of these waters through the swamps already mentioned which cover an area of some 5.34 square miles, or about 11 per cent of the entire watersheds of the ponds. Under the conditions found here much of the water remains long in contact with leaves, grasses and other vegetation from which it absorbs organic matter and iron, and while these substances themselves and the resulting high color are innocuous, a high color is objectionable in a drinking water and should be eliminated. The high color which the water acquires persists until it is exposed to sunlight and other influences in its passage through the ponds. The color is then rapidly reduced by dilution with the rainfall, with water not affected by passage through swamps, and also by bleaching and the other actions that take place in a large reservoir. When the water finally reaches the outlet of the last pond of the series the color is reduced to a comparatively small amount.

The extent of this improvement depends largely, no doubt, upon the length of time that elapses in the passage of the water through the ponds, and if the water in storage should be drawn to a low level so that the colored water of the tributaries could pass through more rapidly, there would be less improvement than at present. For this reason it is important that as the draft increases in the future the color of the waters of the tributary streams shall be reduced by drainage so far as necessary and practicable to prevent them from raising the color of the water of the ponds to an objectionable degree.


LAKEVILLE PONDS
DIAGRAM SHOWING CHANGE IN COLOR
BASED UPON SAMPLES TAKEN SEPTEMBER, 1919 AND APRIL, 1920
Color Scale
Black
Brook
April 1920
September 1919
Entrance of Great to Little Quittacas
New Bedford Pumping Sta.
0
10000
FEET
20000
1
2
3
BLACK BROOK THROUGH GREAT and LITTLE QUITTACAS PONDS TO NEW BEDFORD PUMPING STATION
Color Scale (Parts per 10,000)
Fall Brook, Freetown
Long Pond at County Road
Long Pond Outlet
Taunton Pumping Sta.
Elders Pond
Assawompsett Pond Outlet
Pocksha Pond
Flow toward Assawompsett Outlet
April 1920
September 1919
Flow toward Assawompsett Outlet
0
10000
20000
30000
40000 FEET
FALL BROOK, FREETOWN THROUGH LONG AND ASSAWOMPSETT PONDS TO OUTLET AT NEMASKET RIVER

Protection of the Purity of the Water of the Lakeville Ponds.

For many years after the general introduction of public water supplies was begun in this country little or nothing was known of the possible effects of the pollution of a water supply upon the public health. For the past thirty years, however, the public has grown constantly more insistent upon the maintenance of the purity of its water supplies and upon keeping them free from pollution. It was an early recognition of the requirement that the water supplies be kept free from the wastes of human life and industry which led to the acquisition of large areas of land about the shores of some of these ponds, including those used directly as sources of water supply by the cities of New Bedford, Fall River and Taunton. The city of Fall River, as already indicated, has acquired a large part of the watershed of North Watuppa Pond, and the city of Taunton owns the land bordering Elders Pond, together with a considerable area near the westerly and northerly shores of Assawompsett, while the city of New Bedford, after it had obtained the right to the use of Great and Little Quittacas ponds for its future water supply, set about securing the control of the lands about these two ponds, purchasing some of them and securing others subject to a life tenure by their owners, until at the present time the city controls a large part of the entire watershed of these ponds and their tributaries. But while the lands around Great and Little Quittacas and Elders ponds are largely now in municipal control, practically all of the shores of Long and Pocksha ponds, and most of those of Assawompsett Pond, are still in private hands. The recent surveys show that the total number of dwelling houses, camps and other buildings located on the shores of these ponds, or within their watersheds, amount to about 342. A classification of the lands within approximately 1,400 feet of the shores of these ponds, including the islands, is given in the following table: —

Occupation and Use of Lands adjacent to Long, Assawompsett and Pocksha Ponds.

Land.	Acres.
Cottage and camp lots	228
Private estates and parks	171
Farm land	92
Heavily wooded land	609
Scrub land	1,060
Swamp land	836
Land owned by municipalities	108
Total	3,104

The assessed valuation of the buildings and land privately owned and included in the foregoing table is estimated as follows: —

Buildings	$385,000
Land	304,000
Total	$689,000

If the present conditions in these watersheds should continue, and a much larger population should occupy the shores of these ponds or locate within their watersheds, the quality of their waters would be impaired and their advantages for use as sources of water supply would be largely lost. The control of the lands about the shores of the principal ponds of the group should be secured without delay in order to maintain satisfactory conditions about these ponds in the future. This will become more and more important as greater quantities of water are required for the supply of the cities and towns in this region, and if longer delayed the cost may become excessive.

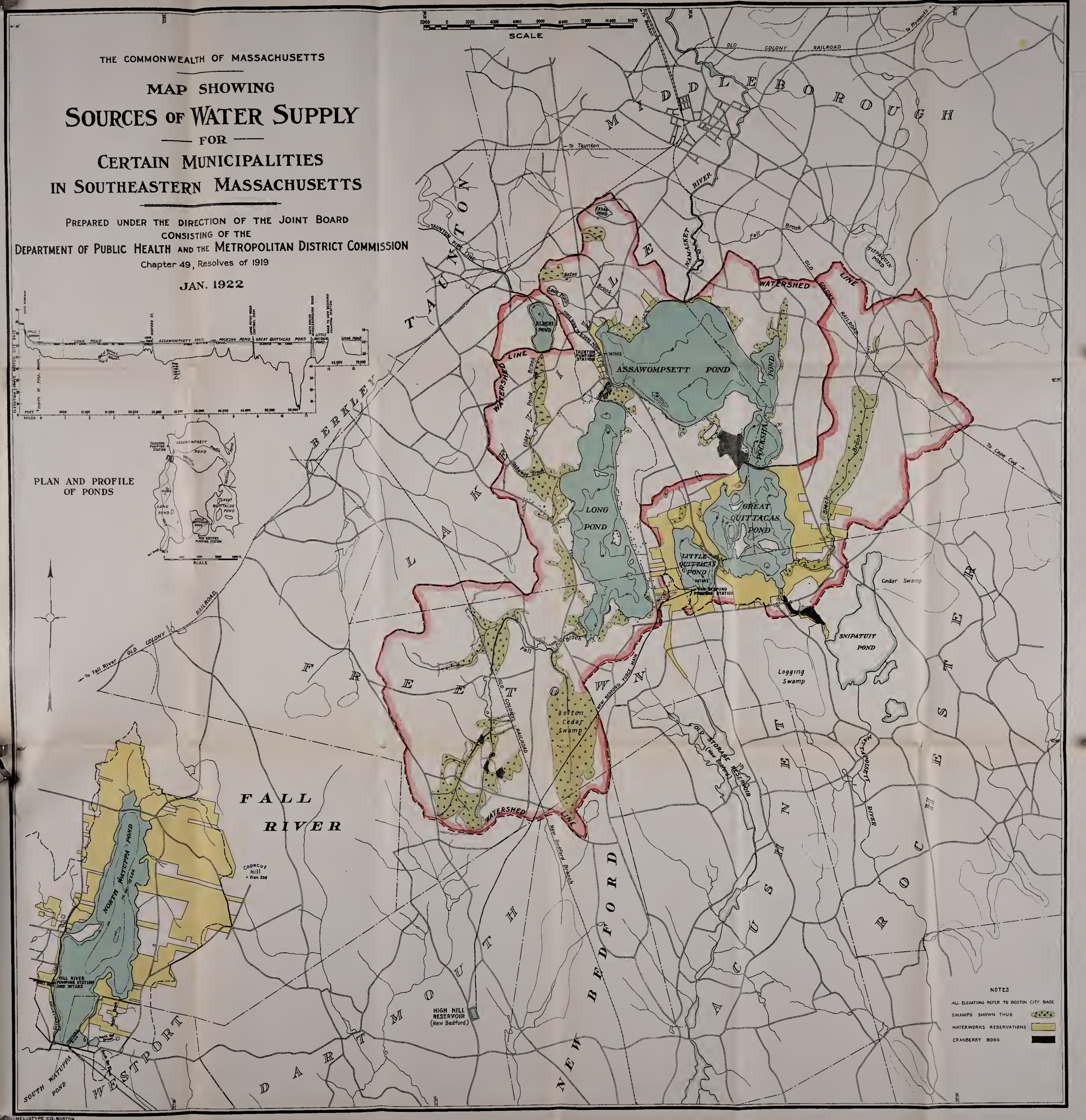
Method of Control of the Lakeville Ponds for Water Supply Purposes.

The improvement and protection of these great natural reservoirs can best be secured by united action of the municipalities interested, the cost to be divided proportionately among those interested. This purpose could be effectively carried out, no doubt, by the creation of a water supply district in this part of the State to include the cities of Fall River, New Bedford and Taunton, and such of the towns in the vicinity of these cities or in the vicinity of the Lakeville Ponds as may desire to join. This would involve the creation of a commission composed of members clothed with sufficient authority for the purpose under a legislative act following the general method adopted at the time of the creation of the Metropolitan Water District. Each municipality would still maintain under such a plan its own individual water system as is the case in the Metropolitan Water District. To the commission would be left all questions relating to securing, protecting and developing to their full extent the water supplies in these ponds. The commission should be authorized to acquire lands within the watersheds and construct and maintain necessary dams and other appurtenances, together with all drainage works needed for the improvement and maintenance of the water in the ponds, in the best condition. They should also have control of the enforcement of rules for the sanitary protection of the water and the policing of the watersheds and the ponds and of the location of all intakes or connections with the ponds. If the areas of land bordering upon the ponds, but as yet unoccupied, should be secured in the beginning, the remaining holdings might be acquired as opportunity should offer, perhaps in part at least after the method followed by the city of New Bedford in acquiring the control of the lands within the watersheds of Great and Little Quittacas ponds, subject to their continued use by the present owners where such an arrangement should be found advantageous or desirable. Some of these holdings, however, are a menace to the purity of the water, and such as are possible sources of danger should be secured and objectionable use thereof prevented at the earliest practicable time. All such questions could be left to the commission, which should be invested with adequate powers for securing and maintaining control of these most important sources of water supply to meet the needs of the large and growing population in the municipalities in this part of the State.

This region is one of the most rapidly growing districts in the State, and this opportunity to secure an excellent water supply adequate for a very long time in the future should not be lost.

Respectfully submitted,

X. H. GOODNOUGH, *Chief Engineer,*
Joint Board on Water Supply
Needs and Resources.



HELIOTYPE CO. BOSTON

APPENDICES

Appendix A.

FINANCIAL STATEMENT CONCERNING THE METROPOLITAN WATER DISTRICT WITH REFERENCE TO AN EXTENSION OF THE WATER SUPPLY WORKS.

By Bertram Brewer, *Principal Assistant Engineer.*

Legislation creating the Metropolitan Water District was enacted in 1895, and work was begun on the Wachusett division of the water works the following year. Early in 1906, or after eleven years had passed, the existing works had been acquired and the Wachusett dam was completed — in fact, the new works were practically finished. All the municipalities now included in the district had joined by that time, with the exception of Swampscott which did not enter until 1909. Up to and including 1906 sums of money amounting to $40,500,000 in all had been borrowed. Since that date varying amounts have been borrowed from year to year for those incidental or minor construction items of work such as will be required as long as the system lasts. The average amount, $174,876, may be said to represent a fair average expenditure for each of those years, and may be used as a basis for forecasting expenditures for incidental or minor construction work from year to year in the future.

By 1920 the district had contributed $36,000,000 for payment of and interest on the total debt of $42,947,000 which had been undertaken, and the accumulated sinking funds in December of that year amounted to about 41 per cent of the total sinking fund debt of $40,500,000 which had been incurred at the close of 1906.

The foregoing facts, together with related information, are shown in the following tables.

The following table is a brief summary of the history of the formation of the Metropolitan Water District as it is now constituted: —

TABLE NO. 1.

MUNICIPALITY.	Entrance Legislation.	Date of Entrance.	Remarks.
Arlington	Acts of 1895, chap. 488	Jan. 31, 1899	Entrance fee, $15,000, and property valued at $15,000.
Belmont	Acts of 1895, chap. 488	1895	In original district.
Boston (including Hyde Park).	Acts of 1895, chap. 488	1895	In original district.
Chelsea	Acts of 1895, chap. 488	1895	In original district.
Everett	Acts of 1895, chap. 488	1895	In original district.
Lexington	Acts of 1895, chap. 488	Feb. 13, 1903	Entrance fee $27,250.
Malden	Acts of 1895, chap. 488	1895	In original district.
Medford	Acts of 1895, chap. 488	1895	In original district.
Melrose	Acts of 1895, chap. 488	1895	In original district.
Milton	Acts of 1902, chap. 307	March 10, 1903	Entrance fee, $10, previous payments by Milton Water Company being consideration in part for admittance.
Nahant	Acts of 1895, chap. 488	Sept. 13, 1898	Entrance fee, $20,000, and an annual payment of $800 until Swampscott shall begin to buy water.
Newton	Acts of 1895, chap. 488	1895	In original district. Takes no water; pays an annual standby charge.
Quincy	Acts of 1895, chap. 488	June 24, 1897	Entrance fee, $5.
Revere	Acts of 1895, chap. 488	1895	In original district.
Somerville	Acts of 1895, chap. 488	1895	In original district.
Stoneham	Acts of 1897, chap. 473	May 23, 1901	Entrance fee, $30,000.
Swampscott	Acts of 1908, chap. 560	May 3, 1909	Entrance fee, $90,000.
Wakefield	Acts of 1902, chap. 488	Not yet entered	- - -
Watertown	Acts of 1895, chap. 488	1895	In original district.
Winthrop	Acts of 1895, chap. 488 Acts of 1898, chap. 295	June 29, 1898	In original district, but membership confirmed by act of 1898.

The sinking fund bonds issued for the metropolitan water supply, with dates of maturity and accumulation of sinking funds as of Dec. 1, 1920, are as follows: —

TABLE NO. 2.

Date of Issue.	Maturity.	Amount of Loan.	December, 1920, Sinking Fund Accumulation.	Remarks.
1895, 1896 and 1897	July, 1935	$13,000,000	$6,831,143 14	1896, Wachusett Aqueduct begun. 1897, Wachusett Reservoir begun and temporary dam built for diverting water.
1898[1]	July, 1938	4,000,000	1,815,707 41	1898, water passed through Wachusett Aqueduct.
1899-1900	July, 1939	4,000,000	1,624,975 24	1900, Wachusett dam begun.
1901[2]	January, 1941	10,000,000	3,595,259 80	- - -
1902	January, 1942	3,500,000	1,191,549 58	- - -
1903 and 1904	January, 1943	2,000,000	621,396 14	1903, Weston Aqueduct completed.
1904	January, 1944	2,000,000	575,861 29	- - -
1905	January, 1945	650,000	203,438 90	1905, Wachusett Reservoir completed.
1906	January, 1946	1,350,000	339,922 14	1906, Wachusett dam completed.
1909	January, 1949	398,000	74,188 98	- - -
1910	January, 1950	500,000	79,722 53	- - -
Totals	. . . . .	$41,398,000	$16,953,165 15	- - -

[1] $5,025,000 paid toward acquiring existing water works.
[2] $7,768,948.80 paid to city of Boston in 1901.

Beginning in 1911, and since that time, only serial bonds have been issued, and the various issues of these bonds have been as follows: —

Date of Issue.	Amount.
1911	$200,000
1912	190,000
1913	-
1914	258,000
1915	490,000
1916	66,000
1917	150,000
1918	-
1919	161,000
1920	34,000
Total	$1,549,000

Net amount outstanding April, 1921, $1,284,000.
Total gross debt incurred, $42,947,000.

The statement was made in the report of 1895, on a metropolitan water supply, to the effect that the financial condition of the water works systems which were to be incorporated into the new district was such that they could, in the years from 1893 to 1903, incur an expenditure for new works, including those for local distribution, of $18,465,000 without any increase in the rates for water that were then current. The study which seemed to warrant these conclusions covered the period from 1883 to 1893.

A very careful investigation would be required of the finances of each of the municipalities included in the district in order to show how nearly the prophecy of 1895 has been fulfilled. As has been stated, the debt for the metropolitan water works has really cost the district only about $36,000,000 to date, and certainly such liquidation as has been accomplished has been so easily borne that rates have been lowered, metering has been carried forward very rapidly, and, notwithstanding all this, in some cases the water department has presented to the city, or has been called upon to present to the city, a large surplus for use for other than water works purposes. Of course, in later years the World War with its aftermath has affected the water works business, and it has cost more to supply water as well as other commodities.

It is an illuminating commentary, however, on the remarkable showing that the district has made, both in procuring and distributing water, that the excess revenue has been large enough to take care of all the added expense and leave in the aggregate a comfortable surplus for new works.

The financial history of the Metropolitan Water District, begun in 1898 and continuing through 1920, furnishes a period of twenty-three years from which to make a forecast at this time of the ability of the district to construct new works and assume the new debt which will be caused thereby. Much of this period has been used in a study which has been carried on according to the following plan, beginning with 1905: —

1. The gross revenue has been obtained for each of the municipalities for the years in question.

2. The expenditure for local construction has been ascertained, including extension of mains, new services, meters, hydrants, etc., and also a similar item of minor construction work on the metropolitan system itself, as indicated by the debt incurred since the time when the Wachusett dam was wholly completed.

3. Maintenance and operating expense, both local and metropolitan, has been obtained for each of the years.

The gross amounts for each year under the several classifications have been reduced to a per capita basis, and from the record so obtained per capita figures for the income and all the various items of outgo have been forecasted for each of the quinquennial years from 1925 to 1970 and these per capita figures have been multiplied by the population forecasts used in the report of the chief engineer for the proper year. The actual cost of interest on as well as amortization of existing debts can be and has been forecasted with considerable accuracy both in the case of local as well as metropolitan debts, and these amounts have also been prepared for subtraction from income.

Finally, by subtracting the sum of the items of outgo from the gross operating income, there remain the amounts which represent the sums which in the aggregate are likely to be available from time to time from municipalities in the Metropolitan Water District for the payment for new works if the water rates continue about as they are at present. Of course, in some of the municipalities in the district the financial conditions are not as good as in others, and this study was of necessity of the district as a whole.

Most of the details of the calculations have necessarily been made with the slide rule, but the figures are in every case within the limits of accuracy necessary for this statement.

This study shows that the total amount available for new works from 1925 to 1970 is likely to be over $160,000,000. In all probability this estimate of $160,000,000, which the cities and towns now in the Metropolitan Water District will accumulate in the aggregate and which can be used for new works, is too small because of additions to income on account of increased consumption which are not included. There will certainly be a growing use of water and a larger income from a given number of people. Undoubtedly there will be other cities and towns which will join the Metropolitan Water District and will share in the expense. This will increase the amount available to pay for new works, and will make the cost less to those municipalities now in the district.

The price for water decreases with a larger use of the commodity, and there are other factors to be taken into account, so that the increased income will not be proportional to the increased use, but it is entirely true that, with the larger use and the certain increase in income which will follow, the estimate of $160,000,000 excess income probably errs on the side of conservatism.

The history of the existing metropolitan water supply sinking fund debt is exceedingly interesting and furnishes a remarkable example of successful financing of a big debt by the sinking fund method of liquidation. The sinking funds have been so well managed that they have grown much faster than was anticipated, partly because of sagacious investments in gilt-edged bonds purchased well below par, and later marked up to par for the sinking fund, partly because of the higher rates which capital has been able to earn in recent years, and partly because of certain receipts[1] which have been added to the sinking funds. The annual additions to the fund due to these various causes have varied from 3.19 per cent in 1906 to 5.14 per cent in 1919, and the average amount from 1905 to 1920, inclusive, was 4.39 per cent. This average is higher than in most cases where sinking funds have been used to amortize public debts, and in this particular case the debt has cost the district less by this method of financing than by the serial bond method.

Notwithstanding the unusual success attending the method of liquidating this particular debt, the sinking fund method of liquidation has been superseded in this State by the serial bond method on account of its simplicity of execution, the greater opportunity for insuring uniformity and regularity in paying for public works, and the saving of interest charges by annual payments to reduce the capital sum.

Coming now to the financing of the proposed extensions of the metropolitan water works, including the reservoir on the Swift River, a study has been made to ascertain how its cost can best be met by the serial bond method. The estimated cost of $60,000,000 will, of course, be distributed as the takings are made and the construction proceeds over a long term of years, probably fourteen or more. For the purposes of this study a distribution of the expenditures has been forecasted and a program of the annual requirements prepared. We have, then, about $160,000,000 surplus in the Metropolitan Water District alone which will accrue during the years from 1925 to 1970 — forty-five years to take care of a debt of $60,000,000.

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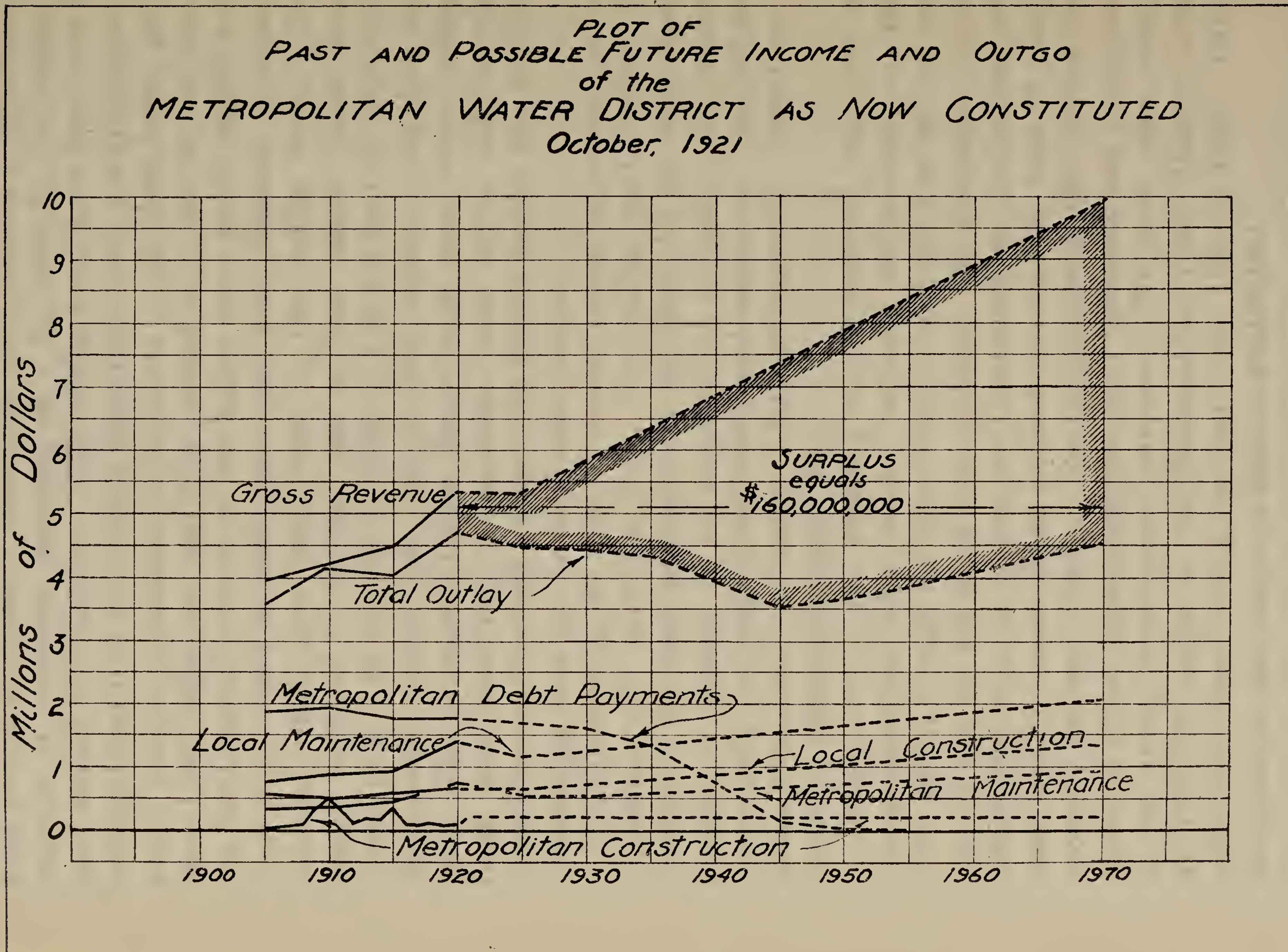
[1] Of this amount there was distributed back to the cities and towns of the district	$219,865 65
For payment of interest, sinking fund requirements and expenses of maintenance and operation there was allotted	568,588 82
To credit of loan fund	349,342 67
To credit of sinking fund	461,218 50
Total receipts to Dec. 31, 1919, ...	$1,599,015 64


PLOT OF
PAST AND POSSIBLE FUTURE INCOME AND OUTGO
of the
METROPOLITAN WATER DISTRICT AS NOW CONSTITUTED
October, 1921
Millons of Dollars
0
1
2
3
4
5
6
7
8
9
10
1900
1910
1920
1930
1940
1950
1960
1970
Gross Revenue
Total Outlay
SURPLUS
equals
$160,000,000
Metropolitan Debt Payments
Local Maintenance
Local Construction
Metropolitan Maintenance
Metropolitan Construction

By the serial bond method of payment of a debt of $60,000,000, based upon equal annual payments, the payments would be as follows: —

Payments on principal	$60,000,000
Interest charges at 4 per cent	55,200,000
Total	$115,200,000

A diagram showing the results of the analysis of income and outgo for the past fifteen years, together with a forecast of the same from 1920 to 1970, is given.

The diagram shows the probable trend of the growth of the surplus of income. Especially noteworthy is the probable rapid increase in the years from 1935 to 1945. It follows that while the total surplus will be sufficient to amortize a very large debt, much larger, in fact, than the one now contemplated, it will be necessary to defer payment or at least pay only a small amount on the principal in the earlier years, as was done in connection with debts of the Metropolitan Water District and the Metropolitan Sewerage District, to avoid raising the water rates during the next few years. By the year 1940, or about that time, depending upon the progress of the work and the interest rate at which the bonds can be sold, the annual surplus will become sufficient to warrant the assumption of full annual payments on the principal of the debt.

In addition to the investigation of the income and outgo of the various municipal water departments, as well as of the finances of the Metropolitan Water District, a particular study has been made of the finances of the cities and towns in the district and in other near-by municipalities for the year 1920. A table appended hereto shows the results of this study. The cities and towns are listed therein in accordance with the total per capita cost of maintenance and operating expenses for that year, with the metropolitan municipalities in one type and those outside the Metropolitan Water District in another. The per capita gross revenue and the per capita cost of all the other items of outgo, as well as that for maintenance, are also given.

It is interesting to note that, of the 32 cities and towns listed, 11 of the 18 municipalities in the Metropolitan Water District and 3 more with only one town intervening, — practically 14 out of the total 18 taking water from the supply of the district, — stand at the head of the list.

The comparatively low cost of the maintenance and operating expenses to the communities which depend upon the metropolitan water supply is a remarkable commentary upon the advantages of co-operative effort in the supply of this necessary commodity. The success attending this effort indicates that the most practicable method by which greater economies can be secured in the future is to be found through enlargement of the Metropolitan Water District by the inclusion of other near-by municipalities and by establishing new district water supplies in other parts of the State.

Financial Statement of Waterworks of the Metropolitan Water District and Near-by Municipalities.

[Arranged in order of 1920 Maintenance Cost.]

Municipality.	Population, 1920.	Per Capita.							
		Gross Revenue.	Maintenance.			Payment on Bonded Debt.			Total Maintenance plus Debt.
			Local.	Metropolitan.	Total.	Local.	Metropolitan.	Total.	
Metropolitan Water District.	1,206,703	–	–	$0 62	$0 62	–	$1 47	$1 47	$2 09
Everett	40,120	$3 26	$0 37	42	79	$0 22	1 00	1 22	2 01
Chelsea	43,184	3 30	56	41	97	34	97	1 31	2 28
Somerville	93,091	2 82	66	41	1 07	01	96	97	2 04
Medford	39,038	2 54	79	29	1 08	–	69	69	1 77
Malden	49,103	2 86	80	33	1 13	20	78	98	2 11
Revere	28,823	3 16	89	36	1 25	70	86	1 56	2 81
Belmont	10,749	3 56	91	38	1 29	23	88	1 11	2 40
Melrose	18,204	3 04	91	38	1 29	1 25	90	2 15	3 44
Arlington	18,665	4 11	1 07	37	1 44	1 88	89	2 77	4 21
Quincy	47,876	5 59	1 09	53	1 62	1 89	1 25	3 14	4 76
Winthrop	15,455	3 74	1 30	34	1 64	1 02	82	1 84	3 48
Winchester[1]	*10,485*	*3 77*	*1 82*	–	*1 82*	*86*	–	*86*	*2 68*
Stoneham	7,873	6 13	1 44	43	1 87	1 28	1 03	2 31	4 18
Watertown	21,457	7 72	1 35	53	1 88	1 19	1 26	2 45	4 33
Boston	748,060	4 58	1 21	75	1 96	08	1 77	1 85	3 81
Lynn	*99,148*	*3 99*	*2 15*	–	*2 15*	*1 28*	–	*1 28*	*3 43*
Waltham	*30,915*	*3 99*	*2 19*	–	*2 19*	*33*	–	*33*	*2 52*
Newton[2]	*46,054*	*4 14*	*2 16*	*04*	*2 20*	*1 93*	*10*	*2 03*	*4 23*
Wakefield	*13,025*	*4 69*	*2 22*	–	*2 22*	*1 41*	–	*1 41*	*3 63*
Lexington	6,350	4 65	1 84	43	2 27	3 03	1 01	4 04	6 31
Saugus	*10,874*	*2 46*	*2 29*	–	*2 29*	*1 07*	–	*1 07*	*3 36*
Weymouth	*15,057*	*3 83*	*2 41*	–	*2 41*	*1 01*	–	*1 01*	*3 42*
Canton	*5,945*	*3 06*	*2 51*	–	*2 51*	*1 29*	–	*1 29*	*3 80*
Milton	9,382	6 75	2 24	42	2 66	1 54	1 00	2 54	5 20
Needham	*7,012*	*4 01*	*2 78*	–	*2 78*	*2 39*	–	*2 39*	*5 17*
Swampscott	8,101	5 48	2 29	50	2 79	1 83	1 20	3 03	5 82
Brookline	*37,748*	*4 29*	*2 83*	–	*2 83*	*1 10*	–	*1 10*	*3 93*
Wellesley	*6,224*	*6 23*	*3 07*	–	*3 07*	*2 80*	–	*2 80*	*5 87*
Braintree	*10,580*	*4 86*	*3 11*	–	*3 11*	*74*	–	*74*	*3 85*
Cambridge	*109,694*	*4 36*	*3 15*	–	*3 15*	*55*	–	*55*	*3 70*
Woburn	*16,574*	*4 00*	*4 77*	–	*4 77*	*2 15*	–	*2 15*	*6 92*
Nahant[3]	1,318	11 16	5 70	97	6 67	–	2 30	2 30	8 97

[1] Gravity supply except for a very small portion which is pumped.
[2] Supplied from its own works up to the present time.
[3] The large summer population not considered.

NOTE. — Municipalities outside the Metropolitan Water District shown in italics.

Appendix B.

REPORT IN REGARD TO FILTRATION OF THE WATER OF LAKE COCHITUATE AFTER RECEIVING WATER DIVERTED FROM FRAMINGHAM RESERVOIR NO. 2, ASHLAND RESERVOIR, HOPKINTON RESERVOIR, ETC.

By H. W. Clark.

Boston, Mass., May 9, 1921.

To the Joint Board on Water Supply Needs and Resources of the Commonwealth, Dr. Eugene R. Kelley, *Chairman*.

Gentlemen: — I make the following report in regard to the storage and filtration of the water of Lake Cochituate and other water, especially that from Framingham Reservoir No. 2, Ashland Reservoir and Hopkinton Reservoir, which, for purposes of this report, it is assumed might be diverted into the lake.

REPORT.

Lake Cochituate, from which water for the supply of Boston began to be taken in 1848, has a water surface of 776 acres, a maximum depth of 72 feet, and an available storage capacity, as estimated by the engineers of the Metropolitan Water Board, of 2,242,000,000 gallons.

The larger portion of the lake is natural, but it has been raised at three different times, first in 1844 and last in 1859, a total of 7 feet, flooding to a depth of about 6 feet a large area of meadow, nearly all of it at the southerly end of the lake. — Report of the State Board of Health for 1890.

Its total contributing watershed was formerly 19.75 square miles, and the lake supplied in ordinary years about 15,000,000 gallons of water daily. By turning a portion of the flow of the

Sudbury River from Framingham Reservoir No. 2 into the lake through Course Brook, the supply taken from it was increased at times to approximately 30,000,000 gallons daily. During the past thirty or more years, however, but little Sudbury River water has been turned into the lake, generally only enough in certain years to keep the lake to a desired level. It was for many years the principal source of supply of Boston, and with the water from the Sudbury River it continued to be used until the introduction of the metropolitan water supply.

Assuming that enough of the Sudbury River water from Framingham Reservoir No. 2, Ashland, Hopkinton and other reservoirs will be turned into the lake to make the total supply that can be taken therefrom approximately 32,000,000 gallons daily, about 15,000,000 gallons would be true Lake Cochituate water and 17,000,000 gallons river water from the reservoirs named. It is also assumed that the supply taken from the lake will be filtered before delivery to the Metropolitan Water District.

It is also assumed in this study that the water from Framingham Reservoir No. 2 and from other reservoirs will not be diverted daily throughout the year, but that it will be passed into the lake in large volumes through the winter and spring months, volumes amounting at times, perhaps, to 35,000,000 or more gallons a day, depending on the capacity of the proposed aqueduct. The total volume of water drawn each year from Lake Cochituate, from 1887 to 1920, inclusive, is shown in a following table (Table No. 1). This table shows that from 1887 up to and including 1897 water drawn from the lake averaged about 15,000,000 gallons daily. Following this there were two years when the volume averaged 4,500,000 gallons daily, and after this water was taken very irregularly, none being drawn in 1910, 1914, 1915 and 1916, and generally but small volumes during all these remaining years up to and including 1920. Since 1887 frequent analyses of the lake water have been made by the Department of Public Health, and a table presenting the average yearly results of these analyses is given below (Table No. 2). It will be seen from the table that the color of the water has varied according to our laboratory determinations from minimums of .13 in 1911, .18 in 1912, and .19 in 1915, to maximums of .41 in 1889, .38 in 1897, and .37 in 1898. The yearly rainfall at Framingham for all these years is also given in a subsequent table (Table No. 3) and indicates that to some extent low color has followed a year or years of low rainfall, although the period of storage of the water in the lake has had a much greater effect. Up to and including the year 1904 the determinations of the color of the samples of water were made by the natural color standard, so called. This standard was inaccurate and gave lower readings than the platinum standard which has been used since January, 1905. On this account it has been necessary in this report to transform all the color readings previous to 1905 to the platinum standard.

Two quite elaborate studies comparing these two standards have been made in different years, — one by Frederick S. Hollis (Boston Water Board Report, 1893), and the other in the laboratories of the Department of Public Health. The conversion table of the latter has been used here and shows that the color of the water taken from the lake during the years 1887 to 1904, inclusive, was considerably greater than the color determinations made during that period seemed to show. The color of the lake water for the period of eleven years, 1887 to 1897, inclusive, when about 15,000,000 gallons were being drawn daily, was .29. During the next twelve years, 1898 to 1909, inclusive, when the lake was still being drawn upon but to a very much less degree, the color averaged .27, and from 1910 to date, during which period but little water has been taken from the lake, the color has averaged .20.

The population upon the watershed of the lake has increased from 13,740 in 1890 to 17,756 in 1920 (Table No. 4), and during this period its watershed has been diminished from approximately 19 square miles to 17.58 square miles, Dug Pond, Dudley Pond and a portion of Cochituate village having been diverted. The increase in population upon the watershed is largely responsible for the increase in the chlorine contents of the water in the lake, shown in the table below. Part of this increase is due, perhaps, to the fact that little Sudbury River water low in chlorine has been diverted to the lake during these years. The chlorine averaged .45 part in 100,000 from 1887 to 1891, inclusive, the first five-year period shown on the table, and averaged .70 from 1916 to 1920, inclusive, the last five-year period shown on the table, — an increase of nearly 80 per cent. The organic matters shown by the determinations of free and albuminoid ammonia and oxygen consumed have fluctuated to a considerable extent, and show on the whole a considerable increase, the averages for the first five-year period shown in the table being .0022, .0196 and .41, respectively, and for the last five-year period, .0037, .0242 and .70, respectively. The total residue and suspended matters have fluctuated also, but with a tendency to increase during recent years when little water has been taken from the lake. The lake water has had through all these years of examination generally a somewhat disagreeable vegetable or earthy taste and odor, these tastes and odors being largely due to abundant growths of Aphanizomenon. Asterionella has been found in great abundance at times and occasionally Anabæna and Dinobryon, but these latter infrequently in such numbers as to give their characteristic taste or odor to the water. The bacterial contents of the lake water have been determined weekly for many years by the Metropolitan Water Board, and these results, together with the results of determinations of microscopic organisms, are shown in a following table (Table No. 5). Occasional bacterial examinations have been made by the Department of Public Health, and a summary of some of these results is given in Table No. 6.

Quite extensive bacterial studies were made in 1911 for the Joint Board (State Board of Health and Metropolitan Water and Sewerage Board) concerning the character of Lake Cochituate water and the advisability of filtration, and the following statement was made by that Board: —

The average number of bacteria per cubic centimeter found in the water of Cochituate Aqueduct as it enters Chestnut Hill Reservoir, for the four years 1906 to 1909, was found to be 5½ per cent of the average number per cubic centimeter in the water entering the lake through the principal inlets; namely, Beaver Dam and Course brooks, through Circular Dam, Snake Brook and the effluent from Pegan Brook filters; and observations made during the present investigation show a similar reduction in numbers and present a very satisfactory water entering Chestnut Hill Reservoir.

This result gives nearly complete assurance that all of the disease germs entering the lake by these inlets are removed by storage in the lake and aqueduct before reaching Chestnut Hill Reservoir. This result together with the continued maintenance of the quality of the water as shown by chemical analysis, and the fact that no injurious effects have in the past been known to result from the use of this water, convince us that the public health does not at present require that the water drawn from Cochituate Lake through the Cochituate aqueduct should be filtered.

The more recent bacterial results taken in connection with the effect of increase in surrounding population, etc., show that this water should, if it continues to be used as a water supply, be filtered (Table No. 6).

It is, of course, impossible to state with accuracy the absolute character of the water that would be diverted. The average analyses of the water of Framingham Reservoir No. 2 from 1905 to date are, however, as given in a following table (Table No. 7), and the average color of the water of Hopkinton and Ashland reservoirs during these years is also given in a following table (Table No. 8). The average color of the waters from these reservoirs has varied considerably during these years, as shown in the tables, the color of the Framingham Reservoir No. 2 water varying from .62 to .91, the Hopkinton Reservoir water from .43 to .74, and the Ashland Reservoir water from .48 to .79. It is perhaps fair to assume — giving due weight to the color of the water of each reservoir — that the water entering Lake Cochituate from these sources would have an average color not greater than .75, and a study of more detailed results than shown on the tables would indicate a maximum color of 1.10.

The principal factor to be considered in the continued use and filtration of Cochituate water and the diverted water is the question of color reduction by storage and filtration, removal of bacterial pollution, organic matter, etc., being in this instance of minor importance; that is, easily accomplished by sand filtration.

Many studies have been made in regard to the reduction of the color of water during storage, and many data have been given by different observers. It is, of course, a well-known fact that the greater the period of storage of water in reservoirs or elsewhere the greater the reduction of color, and it has also been shown that the reduction of color is proportional to the initial color. Decolorization will, if time be given, be carried to such a degree that water stored in clean reservoirs becomes practically colorless. Figures gathered to show the reduction in color of the Wachusett Reservoir water, and assuming that the color of the entering water can be accurately determined, have demonstrated that with a storage of 615 days the color of the water was reduced 66 per cent; with a storage of 355 days, 49 per cent; and with a storage of 280 days, 48 per cent, the first data being collected from results during the years 1908 to 1914, inclusive, the second during 1907, and the third during 1906. During the past five years the average color of the water at the upper end of the reservoir — not the color of the entering streams — has been .25, and at the reservoir outlet, .15, — a reduction of 40 per cent. The average color of the entering streams, namely, the Quinepoxet and Stillwater rivers, during these years was .50

and .36, respectively. Studies of color reduction in Ashland and Hopkinton reservoirs have shown that with 206 days' storage, color has been reduced in Ashland water from 1.00 to .65, and with storage of 234 days in Hopkinton Reservoir, from 1.13 to .60, or 35 and 47 per cent, respectively. In all these studies the reduction of color of the entering water has been without admixture with water already stored within these reservoirs. In each case, however, there has been mixture with the ground water entering each reservoir and the rainfall on the surface of the reservoir, etc. Studies of other clean reservoirs in the State have shown similar color reductions.

During the past four years an especially interesting demonstration of the reduction of color during storage in reservoirs has been given at Wenham Lake, — the water supply of Salem and Beverly, — and the results obtained seem to be particularly applicable to this study. This lake is 320 acres in area,[1] has a maximum depth of 47 feet, and a sand and gravel bottom. It was first used as a water supply in the year 1868. Up to the year 1895 the average color of the lake water was about .07. In that year a reservoir was built on Longham Brook and a conduit constructed to convey the Longham Brook water to Wenham Lake. Following this, the color of the lake water was increased to an average of .14 from 1895 to 1904, inclusive, and to .28 from 1905 to 1916, inclusive, the Longham Reservoir water having a color of 1.00 or greater. Beginning in 1917, water from the Ipswich River also began to be pumped to the lake in periods of high flow of the river, and a following table (Table No. 9) shows the volume of Longham Reservoir water and Ipswich River water passed into the lake during the years 1917, 1918, 1919 and 1920, together with the average color of the waters coming from these two sources during each year, and the color of the water pumped to Salem and Beverly. Ipswich River water, according to the act creating the Salem–Beverly Water Supply Board, can only be taken between December 1 and June 1, and only when the flow of the river is 20,000,000 gallons a day or greater.

It will be seen by the table that the average color of the Ipswich River water pumped during these four years was .76, .92, 1.01 and .82, respectively, and the average color of Longham Reservoir water 1.32, 1.29, 1.07 and 1.23, respectively. The average color of the mixed water coming from these two sources into the lake during these four years — taking into consideration

[1] Longley, N. E. W. W. Jour., March, 1916, says "250 acres."

the volume of each — was probably about 1.07, 1.15, 1.06 and 1.08, while the average color of the lake water as pumped to its consumers was .35, .37, .37 and .26, respectively. The maximum color of the water as pumped from the lake was .64, May, 1917; .52, September, 1918; .48, February and December, 1919; and .46, March and August, 1920.

During 1917 the water coming into the lake from these two sources, namely, the Ipswich River and Longham Reservoir, was equal to 70 per cent of that pumped from the lake; in 1918, 66 per cent; in 1919, 72 per cent; and in 1920, 46 per cent. The average color of the mixed Longham Reservoir and Ipswich River water for the four years noted was about 1.09, and of the water pumped from the lake, .34; that is, taking the four years together there was an apparent color reduction of 69 per cent by mixture with the true lake water and the physical and chemical phenomena due to storage, this reduction being, however, not more than 30 to 40 per cent during certain short periods when large volumes of river water were pumped to the lake. A mixture of the three waters, that is, the true lake water, the Longham Reservoir water, and the Ipswich River water, allowing for the proportional volume of each, would have produced theoretically a water with an average color of about .77 in 1917, 1918 and 1919, and .52 in 1920. As a matter of fact, the average color of the water at the pumping station for the first three of these years was less than one-half these theoretical colors, — a reduction of more than 50 per cent, and during 1920 exactly 50 per cent. About 7,000,000 gallons of water a day as an average are pumped from the lake.

There is no reason to suppose that the water coming from the reservoirs stated, namely, Framingham No. 2, Ashland and Hopkinton, and diverted to Lake Cochituate, would have a color as great as the mixed water of Longham Reservoir and the Ipswich River now flowing or pumped to Wenham Lake. It is probable that the maximum color of this diverted water would not be over 1.10, — and this only happening occasionally, judging from the individual analyses of past years, — and that the average color will not be greater than .75. If approximately 17,000,000 gallons of this water were diverted to the lake daily at its southern extremity, namely, coming in through Course Brook or Beaver Dam Brook, 2½ miles from Cochituate Aqueduct, this water would be, theoretically, about 100 days in reaching the intake of this aqueduct if it moved in a solid body through the lake.

In a report of the Joint Board for 1912, the statement is made that "in the period of greatest flow of water from the south end of the lake of which we have record, it required about one and one-half months for a particle of water entering the lake from Beaver Dam Brook to reach the entrance of the aqueduct, and that during probably three-quarters of the year, when no water is wasting from the lake and the aqueduct is drawing all it can convey, the time required for a particle of water to pass up the lake from the southerly end would be as much as six months. The time required for a particle of water entering from Snake Brook to reach the aqueduct is estimated to be about four-tenths of the above periods."

The distance from the mouth of Course Brook to the aqueduct is approximately the same as from Beaver Dam Brook to the aqueduct. The movement of the water through the lake, however, would be governed not only by the volume entering at one time and the distance to be traveled, but by stratification, by the seasonal overturn of the lake water, by the direction and force of the wind, by the temperature of the water and of the air, by the path of the current through the lake, and by its degree of admixture with the true lake water. It is evident, moreover, that the water diverted from the reservoirs will be passed into the lake during certain periods of the year only, and during these periods in volumes perhaps approximating 25,000,000 or 35,000,000 gallons daily, depending on the capacity of the diversion works. Coming in in this way the time of storage in or passage through Lake Cochituate would be materially shortened, and at times would not be greater, probably, than the period mentioned by the Joint Board of 1912 in regard to the maximum flow from Beaver Dam Brook, namely, 45 days.

Lake Cochituate is fed by four brooks and, of course, receives much water through the ground and from the surface of the ground immediately around it. The four brooks are Beaver Dam, Course and Snake brooks (already named) and Pegan Brook. The water of three of these is generally quite highly colored, but by storage it is materially lessened as our analytical results of many years show. Few old records are obtainable of the color of the entering water. In a special report of the State Board of Health (1895), entitled "Report upon a Metropolitan Water Supply," the statement is made that "the streams which feed Lake Cochituate supply water of nearly the same character as those which feed the storage reservoirs upon the Sudbury River; but Lake Cochituate furnishes a water having but little color, while Sudbury River reservoirs furnish water having a marked brownish tinge. This difference is due to the fact that Lake Cochituate has a much larger storage capacity in proportion to the quantity of water entering it than the reservoirs upon the Sudbury River, and the water in this lake, therefore, has the opportunity to become very much improved by bleaching and other changes which take place from long storage." The waters of Pegan Brook receiving considerable drainage are filtered before entering the lake. The average color of the waters of all these brooks for the past ten years, 1911 to 1920, inclusive, is shown in a following table. (Table No. 10.) It will be seen that the colors are comparatively high, especially of the brooks furnishing the larger volume of water. When 15,000,000 gallons were being taken from Cochituate daily, this water, with an average color of perhaps .60 or .65, was during storage and by addition of ground water, etc., reduced in color to an average of .28, but with maximums of .35 and .41 for certain years of that period. If enough water is diverted to the lake so that 32,000,000 gallons are taken from it daily, the period of storage of the true lake water will be materially reduced — theoretically — about one-half, and it is probable that under such conditions its color will not get below .38 as an average, — an apparent color reduction of about 40 per cent. The water diverted coming in with an average color of perhaps 75 will undoubtedly, judging from results from other reservoirs, especially the Wenham Lake results, lose on an average at least 40 per cent of its color before reaching the entrance of the aqueduct, or at this point it would, without dilution, have a color of .45. It will be mixed with nearly an equal volume of true Cochituate water which enters the lake through various brooks with a color somewhat less. On the whole, it seems reasonable to assume that the color of the water at the aqueduct will seldom be greater than .40 to .45, even at periods when the greatest volume of water is being diverted from the reservoirs, and at times when small volumes are being diverted it will be as low as .35.

In making this assumption it is necessary for confirmation to again turn to Wenham Lake results. From this lake, with an available storage of 900,000,000 gallons to a depth of 14 feet, and increased to about 1,200,000,000 gallons by drawing the lake down 20 feet, approximately 7,000,000 gallons are pumped daily, while from Lake Cochituate, with an available storage of 2,242,000,000 gallons, it is proposed to draw four and one-half times as much daily, or 32,000,000 gallons. At Wenham Lake the maximum amount of Longham Reservoir and Ipswich River water coming into the lake any one year has been 1,787,000,000 gallons, while it is proposed to divert to Lake Cochituate about three and one-half times this volume, or approximately 6,200,000,000 gallons, yearly. At Wenham Lake the diverted water, high in color, mixes with approximately one-third its volume of the true lake water, low in color, while at Cochituate the true lake water will be comparatively high in color. At Wenham Lake, Ipswich River water travels approximately 1 mile to the pumping station, and Longham Reservoir water three-fifths of a mile. At Lake Cochituate the diverted water would travel about 2½ miles. It is apparent that the period of storage at Lake Cochituate should, under these conditions of entering volume and distance traveled, be considerably shorter than the average period of storage of the two waters entering Wenham Lake, — perhaps only two-thirds as great.

Taking all these factors into consideration, and knowing there is an apparent average color reduction of 65 per cent at Wenham Lake by storage and mixture with the true lake water with minimum reductions of 35 and 40 per cent, it is safe to assume an average 40 per cent reduction at Cochituate. The water coming to the aqueduct with an average color of .40 to .45, and with numbers of bacteria no greater than shown in the table, indicating but slight pollution, could be filtered through sand filters at a rate of 5,000,000 gallons per acre daily and be made absolutely safe. The filtered water would undoubtedly be fairly satisfactory in taste and odor all the time, and absolutely satisfactory in these qualities, except occasionally at times of maximum growths of taste and odor producing organisms in the reservoir. The filters would remove on an average approximately 35 per cent of the color of the applied water, making the average color of the effluent about .25 with a maximum of .35 if the maximum color of the applied water is occasionally above .50, as may occur. Water of this color would not be entirely satisfactory perhaps to the Metropolitan District, as the average color of the water delivered in Boston for the past ten years has been about .15. The filtered water, however, would be almost always mixed with at least an equal volume of water from the Sudbury and Wachusett reservoirs, and its color lowered by this dilution to an acceptable point.

Many sand filters furnish data showing that much greater color removal than here estimated would be accomplished by sand filtration of this water. Such filters, however, are generally operated either at a very low and uneconomical rate, or ground water mixes with their effluent, or they receive water containing enough iron to oxidize and precipitate and thus aid color removal very materially, or water, the coloring matter of which is in a more colloidal state than I believe would be the case at Lake Cochituate. All things considered, it seems probable that the filtration results obtained at Wenham Lake are more directly applicable to the Cochituate problem than any other available data, and fortunately an experimental filter 1/200 of an acre in area and containing 5 feet in depth of sand has been operated at Wenham Lake a large part of the time since July, 1916. The average color of the water applied to the filter has been .42, and of the effluent, .28, — a reduction of 33 per cent. The maximum color of the applied water has been .62, and the maximum color of the effluent .39. More than half of the samples of applied water and effluent, moreover, have been collected during the colder months of each year when the color of the lake water has been the highest and conditions of weather least favorable to the most efficient filtration.

Sand filters of the usual construction and operated at the rate of 5,000,000 gallons per acre daily would, besides reducing the color to the extent estimated, render the water clear, free from turbidity, low in organic matter and safe bacterially. Approximately 40 per cent of the organic matter, determined as albuminoid ammonia, would be removed, and more than 98 per cent of the bacteria. This water is at the present time but slightly polluted bacterially, and it is not probable that the true lake water and the entering or diverted water would for many years to come become polluted to such a degree that the rate of filtration would have to be decreased or the use of chlorine resorted to. There is no reason to suppose, moreover, that sand filtration would in this instance increase the carbonic acid of the water materially, and hence would not cause the water to be much, if any, more corrosive to service pipes than it is now.

TABLE NO. 1. — *Statistics in Regard to the Use of Water from Lake Cochituate, 1887 to 1920, inclusive.*

YEAR.	Number of Days Water taken.	Volume of Water used (Gallons).
1887	–	4,802,121,000
1888	–	4,968,503,000
1889	–	5,570,424,000
1890	–	5,722,174,000
1891	–	5,508,180,000
1892	–	5,464,800,000
1893	–	5,623,532,000
1894	–	5,520,092,000
1895	–	5,654,766,000
1896	–	5,731,790,000
1897	–	5,738,704,000
1898	143	1,662,575,000
1899	102	1,702,725,000
1900	215	4,466,140,000
1901	307	5,434,850,000
1902	259	4,440,225,000
1903	282	3,875,935,000
1904	259	5,484,144,000
1905	249	5,589,245,000
1906	237	4,850,120,000
1907	216	4,160,270,000
1908	108	1,473,882,000
1909	126	2,472,510,000
1910	–	–
1911	210	3,475,600,000
1912	100	770,900,000
1913	62	885,300,000
1914	–	–
1915	–	–
1916	–	–
1917	29	125,400,000
1918	12	154,500,000
1919	65	713,900,000
1920	29	287,900,000

Table No. 2. — *Yearly Average Analyses of the Water of Lake Cochituate*

[Parts in 100,000.]

Year.	Color.		Residue on Evaporation.	Ammonia.			Chlorine.	Oxygen consumed.	Hardness.
	Natural Standard.	Platinum Standard.		Free.	Albuminoid. Total.	Albuminoid. In Suspension.			
1887 . . .	.21	.26	5.08	.0017	.0186	–	.44	–	–
1888 . . .	.19	.25	4.90	.0033	.0217	–	.43	–	–
1889 . . .	.33	.41	5.08	.0025	.0210	.0033	.46	–	–
1890 . . .	.21	.26	4.74	.0016	.0184	.0035	.49	–	2.4
1891 . . .	.24	.30	4.66	.0017	.0182	.0037	.42	–	1.8
1892 . . .	.15	.21	4.61	.0018	.0168	.0035	.48	–	2.0
1893 . . .	.21	.26	4.64	.0015	.0168	.0030	.46	.39	2.0
1894 . . .	.20	.25	4.76	.0008	.0163	.0026	.51	.37	2.1
1895 . . .	.25	.31	5.08	.0015	.0178	.0025	.51	.42	2.1
1896 . . .	.28	.33	4.89	.0012	.0176	.0031	.50	.45	1.9
1897 . . .	.31	.38	5.11	.0012	.0202	.0030	.52	.44	2.1
1898 . . .	.30	.37	4.92	.0016	.0203	.0030	.47	.45	2.1
1899 . . .	.22	.27	4.74	.0020	.0232	.0039	.43	.43	1.7
1900 . . .	.14	.20	4.54	.0033	.0222	.0035	.43	.37	1.8
1901 . . .	.26	.32	5.17	.0042	.0239	.0039	.41	.48	2.1
1902 . . .	.25	.31	4.77	.0028	.0192	.0031	.42	.46	1.9
1903 . . .	.23	.28	4.91	.0020	.0188	.0029	.46	.44	2.0
1904 . . .	.21	.26	4.85	.0025	.0198	.0029	.50	.43	2.1
1905 . . .	–	.25	4.80	.0026	.0213	.0046	.50	.42	1.8
1906 . . .	–	.26	5.21	.0030	.0223	.0041	.51	.46	1.8
1907 . . .	–	.24	5.19	.0036	.0233	.0057	.51	.42	2.0
1908 . . .	–	.26	5.40	.0023	.0218	.0058	.59	.43	2.1
1909 . . .	–	.24	5.21	.0029	.0221	.0049	.54	.42	2.0
1910 . . .	–	.23	5.90	.0021	.0205	.0041	.61	.37	2.2
1911 . . .	–	.13	5.97	.0021	.0199	.0041	.65	.34	2.4
1912 . . .	–	.18	6.35	.0014	.0278	.0104	.69	.40	2.6
1913 . . .	–	.20	6.93	.0025	.0328	.0141	.71	.39	2.6
1914 . . .	–	.23	6.25	.0025	.0260	.0072	.68	.40	2.3
1915 . . .	–	.19	6.12	.0068	.0238	.0052	.66	.39	2.4
1916 . . .	–	.23	6.67	.0060	.0236	.0054	.72	–	2.5
1917 . . .	–	.20	6.56	.0044	.0239	.0048	.71	–	2.4
1918 . . .	–	.19	6.41	.0029	.0262	.0070	.73	–	2.5
1919 . . .	–	.20	6.46	.0024	.0270	.0064	.70	–	2.7
1920 . . .	–	.22	6.12	.0027	.0204	.0044	.64	–	2.6

Table No. 3. — *Rainfall, in Inches, Framingham Rain Gage.*

Year.	Rainfall (Inches).	Year.	Rainfall (Inches).
1887	42.45	1904	41.70
1888	59.94	1905	41.83
1889	53.08	1906	41.54
1890	52.72	1907	42.10
1891	49.11	1908	34.14
1892	41.90	1909	40.70
1893	48.90	1910	34.64
1894	40.29	1911	36.85
1895	51.40	1912	39.62
1896	43.21	1913	44.45
1897	44.89	1914	35.33
1898	54.27	1915	43.04
1899	36.59	1916	39.29
1900	48.90	1917	40.79
1901	54.70	1918	39.77
1902	48.19	1919	45.78
1903	43.25	1920	50.33

Table No. 4. — *Cochituate Watershed. — Sanitary Census by Districts for 1920.*

District.	Population.			
	Permanent.	Summer.	In dwellings not connected with sewer.	
			Total.	Per Square Mile.
Cochituate watershed:				
Snake Brook	643	212	643	179.6
Pegan Brook	4,747	48	240	107.1
Course Brook	788	–	588	162.9
Beaver Dam Brook	11,578	66	1,757	215.6
Totals	17,756	326	3,228	183.6

TABLE No. 5. — *Bacteria and Microscopic Organisms in Lake Cochituate Water.*

Year.	Bacteria per Cubic Centimeter.	Standard Units of Microscopic Organisms.
1898	145	544
1899	104	992
1900	113	1,139
1901	149	697
1902	168	937
1903	120	860
1904	172	838
1905	396	904
1906	145	1,042
1907	246	909
1908	138	1,073
1909	229	632
1910	–	556
1911	204	1,382
1912	450	3,887
1913	243	2,622
1914	201	2,032
1915	201	1,900
1916	–	2,708
1917	112	638
1918	194	2,766
1919	85	4,747

TABLE No. 6. — *State Department of Public Health Results of Bacterial Examinations of Samples of Water from Lake Cochituate.*

Date.	Bacteria per Cubic Centimeter. 24 Hours, 37° C.		B. Coli in —	
	Total.	Red.	1 c. c.	100 c. c.
May 1, 1911	10	6	0	+
Oct. 18, 1911	1	0	0	+
Oct. 18, 1911	0	0	0	+
Nov. 14, 1911	3	0	0	+
Nov. 14, 1911	0	0	0	+
Nov. 14, 1911	0	0	0	+
Nov. 14, 1911	0	0	0	+
Nov. 14, 1911	0	0	0	+
Nov. 14, 1911	0	0	0	+
Nov. 22, 1911	12	3	0	0
Nov. 24, 1911	25	2	+	+
Nov. 24, 1911	16	1	0	+
Nov. 24, 1911	0	0	0	+
Nov. 24, 1911	0	0	0	0
Nov. 24, 1911	15	5	+	+
Dec. 4, 1911	20	12	0	+
Dec. 4, 1911	1	0	0	+
Dec. 4, 1911	0	0	0	+
Dec. 6, 1911	0	0	0	+
June 24, 1913	8	5	+	+
June 24, 1913	20	10	0	+
June 24, 1913	18	3	0	+
June 24, 1913	8	0	0	+
June 24, 1913	8	1	0	+
June 24, 1913	20	0	0	+
July 21, 1913	5	1	0	+
July 21, 1913	20	13	0	+
July 21, 1913	28	14	0	+
July 21, 1913	12	5	+	+
July 21, 1913	9	7	0	+
July 21, 1913	16	4	0	+
Aug. 19, 1913	150	5	+	+
Aug. 19, 1913	120	10	+	+
Aug. 19, 1913	160	0	0	+

+ indicates present. 0 indicates none found.

TABLE No. 6. — *State Department of Public Health Results of Bacterial Examinations of Samples of Water from Lake Cochituate* — Concluded.

Date.	Bacteria per Cubic Centimeter. 24 Hours, 37° C.		B. Coli in —	
	Total.	Red.	1 c. c.	100 c. c.
Aug. 19, 1913	100	20	+	+
Aug. 23, 1913	200	0	+	+
Aug. 23, 1913	225	5	+	+
March 12, 1914	36	32	0	+
March 12, 1914	7	3	0	0
April 15, 1914	18	3	0	+
April 15, 1914	20	15	0	0
Sept. 13, 1917	3	0	0	-
Sept. 13, 1917	2	0	0	+

+ indicates present. 0 indicates none found.

TABLE No. 7. — *Yearly Average Analyses of Framingham Reservoir No. 2.*

[Parts in 100,000.]

Year.	Color.	Residue on Evaporation.	Ammonia.			Chlorine.	Oxygen consumed.	Hardness.
			Free.	Albuminoid. Total.	Albuminoid. In Suspension.			
1905	.79	4.28	.0044	.0228	.0022	.32	.87	.9
1906	.70	4.10	.0034	.0217	.0022	.32	.76	.9
1907	.65	4.34	.0021	.0194	.0019	.33	.72	1.0
1908	.66	4.17	.0027	.0197	.0027	.35	.68	1.0
1909	.69	4.34	.0031	.0212	.0024	.34	.76	1.0
1910	.67	4.66	.0039	.0237	.0027	.40	.77	1.2
1911	.62	4.90	.0041	.0242	.0026	.42	.77	1.4
1912	.89	5.50	.0064	.0275	.0024	.44	.96	1.6
1913	.85	5.55	.0047	.0303	.0034	.44	.94	1.6
1914	.78	5.09	.0049	.0281	.0043	.44	.83	1.3
1915	.91	5.60	.0060	.0320	.0053	.46	.81	1.4
1916	.85	4.85	.0057	.0272	.0030	.42	-	1.2
1917	.72	5.27	.0048	.0253	.0032	.43	-	1.2
1918	.69	5.13	.0050	.0266	.0035	.44	-	1.6
1919	.79	5.66	.0060	.0265	.0025	.54	-	1.5
1920	.79	6.40	.0067	.0230	.0037	.62	-	1.6

TABLE No. 8. — *Yearly Average Color of Hopkinton Reservoir and of Ashland Reservoir.*

Year.	Color.	
	Hopkinton Reservoir.	Ashland Reservoir.
1905	.43	.48
1906	.53	.56
1907	.55	.57
1908	.54	.56
1909	.47	.55
1910	.48	.58
1911	.43	.48
1912	.69	.71
1913	.60	.67
1914	.50	.60
1915	.65	.60
1916	.74	.79
1917	.66	.65
1918	.53	.61
1919	.58	.56
1920	.60	.66

TABLE No. 9. — *Statistics, Salem and Beverly Water Supply.*

Total storage, Wenham Lake (million gallons), 2,000.
Upper 20 feet of storage, Wenham Lake (million gallons), 1,200.
Ipswich River Pumping Station to Salem Pumping Station = 3,000 feet of 36-inch pipe; length of lake = 5,000 feet.
Longham Outlet to Salem Pumping Station = 3,200 feet.

Year.	Million Gallons.		Color.		
	Pumped from Ipswich River.	Drawn from Longham Reservoir.	Ipswich River.	Wenham Lake.	Longham Reservoir.
1917	696.7	930.7	.76	.35	1.32
1918	636.9	1,016.5	.92	.37	1.29
1919	432.6	1,354.4	1.01	.37	1.07
1920	441.0	800.3	.82	.26	1.23

Pumped from Lake.

1917 . . . . . 2,324.9 million gallons, 70 per cent of this being Longham Reservoir and Ipswich River water.
1918 . . . . . 2,520.6 million gallons, 66 per cent of this being Longham Reservoir and Ipswich River water.
1919 . . . . . 2,483.0 million gallons, 72 per cent of this being Longham Reservoir and Ipswich River water.
1920 . . . . . 2,675.1 million gallons, 46 per cent of this being Longham Reservoir and Ipswich River water.

TABLE No. 10. — *Yearly Average Color of Four Brooks entering Lake Cochituate, 1911 to 1920, inclusive.*

Year.	Color.			
	Beaver Dam Brook.	Course Brook.	Pegan Brook.	Snake Brook.
1911	.96	.70	.20	.42
1912	.96	.71	.21	.48
1913	1.00	.72	.19	.47
1914	.87	.79	.16	.41
1915	1.47	1.09	.21	.53
1916	1.05	.83	.08	.45
1917	.79	.65	.11	.37
1918	.74	.68	.14	.41
1919	.74	.66	.14	.39
1920	.62	.61	.15	.41

Appendix C.

ANALYSES OF SAMPLES OF WATER FROM PRESENT AND PROPOSED SOURCES OF WATER SUPPLY OF THE METROPOLITAN WATER DISTRICT.

Swift River at West Ware.

[Parts in 100,000.]

Date.	Color.	Residue on Evaporation.		Ammonia.				Chlorine.	Oxygen consumed.	Hardness.	Iron.
					Albuminoid.						
		Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.				
1920.											
November . .	.32	5.10	1.30	.0020	.0128	.0124	.0004	.18	.46	1.1	.045
December . .	.35	5.55	1.85	.0023	.0095	.0082	.0013	.18	.45	1.2	.020
1921.											
April . . .	.25	3.80	1.00	.0018	.0108	.0100	.0008	.14	.48	1.1	.010
May . . .	.30	2.90	1.00	.0004	.0082	.0078	.0004	.08	.58	1.3	.015
June . . .	.19	3.40	1.40	.0024	.0128	.0096	.0032	.15	.23	0.8	.030
July . . .	.45	4.60	1.80	.0024	.0130	.0106	.0024	.12	.65	1.0	.025
September . .	.20	3.30	1.50	.0036	.0136	.0132	.0004	.18	.44	1.0	.030
October . .	.28	4.40	1.60	.0002	.0010	–	–	.14	.48	1.1	.027
November . .	.37	4.80	1.80	.0012	.0118	–	–	.17	.48	1.4	.020
Average .	.30	4.21	1.47	.0018	.0104	.0102	.0013	.15	.47	1.1	.025

West Branch of Swift River at Enfield.

Date.	Color.	Residue: Total.	Residue: Loss on Ignition.	Ammonia: Free.	Albuminoid: Total.	Albuminoid: Dissolved.	Albuminoid: Suspended.	Chlorine.	Oxygen consumed.	Hardness.	Iron.
1920.											
November . .	.20	4.50	1.50	.0016	.0096	–	–	.18	.46	1.0	–
December . .	.15	3.75	1.35	.0020	.0081	.0060	.0021	.14	.27	0.7	.012
1921.											
March . . .	.12	4.30	1.60	.0006	.0064	.0062	.0002	.19	.25	0.8	.012
April . . .	.15	4.40	1.70	.0006	.0076	.0074	.0002	.14	.35	0.8	.008
May . . .	.12	3.00	1.10	.0002	.0072	.0046	.0026	.09	.28	0.6	.007
June . . .	.09	3.60	1.00	.0010	.0068	–	–	.14	.10	0.5	.018
July . . .	.24	3.20	0.60	.0020	.0092	.0072	.0020	.11	.40	0.6	.012
September . .	.15	3.90	1.40	.0076	.0096	–	–	.18	.22	0.6	.018
October . .	.25	4.10	1.60	.0000	.0084	–	–	.16	.43	1.3	.010
November . .	.30	3.50	1.10	.0004	.0076	–	–	.17	.50	1.4	.018
Average .	.18	3.83	1.30	.0016	.0080	.0063	.0014	.15	.33	0.8	.013

East Branch of Swift River at Greenwich.

[Parts in 100,000.]

Date.	Color.	Residue on Evaporation.		Ammonia.				Chlorine.	Oxygen consumed.	Hardness.	Iron.
		Total.	Loss on Ignition.	Free.	Albuminoid.						
					Total.	Dissolved.	Suspended.				
1920.											
November	.70	4.10	2.20	.0056	.0204	.0192	.0012	.22	.72	1.1	.062
December	.55	4.45	1.25	.0036	.0126	.0112	.0014	.20	.51	1.0	.026
1921.											
March	.32	4.40	2.10	.0018	.0096	.0084	.0012	.22	.58	1.0	.015
April	.35	4.30	1.50	.0040	.0236	.0196	.0040	.18	.72	0.6	.010
May	.50	3.70	1.50	.0004	.0116	.0094	.0022	.09	.82	0.6	.015
June	.40	4.30	1.90	.0028	.0200	.0156	.0044	.12	.52	1.1	.020
July	.72	4.80	2.10	.0064	.0186	.0146	.0040	.12	1.04	1.3	.025
September	.37	5.20	2.40	.0048	.0188	.0180	.0008	.12	.76	1.0	.020
October	.38	3.60	1.60	.0022	.0142	–	–	.14	.55	1.1	.020
November	.40	4.50	1.80	.0028	.0126	–	–	.18	.58	1.0	.035
Average	.47	4.34	1.84	.0034	.0162	.0145	.0024	.16	.68	1.0	.025

Middle Branch of Swift River at Greenwich.

1920.											
November	.30	4.00	1.10	.0056	.0156	.0148	.0008	.20	.40	1.0	.035
December	.33	4.30	1.70	.0031	.0121	.0113	.0008	.15	.43	0.9	.017
1921.											
March	.20	3.70	1.50	.0008	.0080	.0068	.0012	.16	.32	0.8	.020
April	.27	4.00	1.70	.0006	.0104	.0098	.0006	.12	.68	0.8	.010
May	.30	3.00	1.20	.0006	.0094	.0080	.0014	.09	.56	1.0	.015
June	.25	5.00	2.20	.0012	.0108	.0084	.0024	.09	.31	0.6	.030
July	.52	3.60	0.80	.0030	.0126	.0102	.0024	.12	.68	1.0	.025
September	.20	4.10	1.90	.0056	.0160	.0116	.0044	.18	.42	1.0	.015
October	.34	4.60	1.80	.0018	.0128	–	–	.15	.48	1.1	.012
November	.40	5.40	2.10	.0002	.0124	–	–	.16	.55	1.3	.025
Average	.31	4.17	1.60	.0023	.0120	.0101	.0018	.14	.48	1.0	.020

Millers River above Athol.

[Parts in 100,000.]

Date.	Color.	Residue on Evaporation.		Ammonia.				Chlorine.	Oxygen consumed.	Hardness.	Iron.
					Albuminoid.						
		Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.				
1921.											
June	.70	3.90	1.80	.0016	.0298	.0250	.0048	.14	0.80	–	–
July	1.15	6.40	3.40	.0046	.0268	.0228	.0040	.18	1.75	–	–
August	.98	6.00	3.40	.0024	.0276	.0222	.0054	.32	1.88	–	–
September	.70	5.00	2.10	.0006	.0246	.0210	.0036	.30	0.76	–	–
October	.50	5.20	2.20	.0004	.0178	.0170	.0008	.26	0.64	–	–
November	.54	5.70	3.00	.0012	.0160	.0140	.0020	.39	0.80	–	–
Average	.76	5.37	2.65	.0018	.0237	.0203	.0034	.27	1.71	–	–

Ware River at Coldbrook.

1920.											
November	.60	5.10	2.60	.0036	.0164	.0160	.0004	.29	.72	1.4	.032
December	.53	4.90	2.10	.0024	.0156	.0137	.0019	.22	.52	0.8	.027
1921.											
March	.35	4.10	1.80	.0012	.0148	.0136	.0012	.20	.46	0.8	.015
April	.48	3.20	1.10	.0016	.0132	.0094	.0038	.12	.80	0.8	.015
May	.57	4.10	1.50	.0008	.0144	.0142	.0002	.15	.88	0.8	.025
June	.45	4.70	1.60	.0036	.0204	.0172	.0032	.22	.44	0.5	.070
July	.93	5.10	1.90	.0030	.0212	.0174	.0038	.14	1.20	0.5	.050
September	.54	4.00	1.70	.0052	.0244	.0218	.0026	.13	.56	0.6	.060
October	.60	5.20	2.10	.0008	.0178	–	–	.16	.84	1.1	.035
November	.62	5.40	2.00	.0014	.0118	–	–	.22	.90	1.7	.050
Average	.57	4.58	1.84	.0024	.0170	.0154	.0021	.19	.73	0.9	.038

Stillwater River.

[Parts in 100,000.]

Date.	Color.	Residue on Evaporation. Total.	Residue on Evaporation. Loss on Ignition.	Ammonia. Free.	Ammonia. Albuminoid. Total.	Ammonia. Albuminoid. Dissolved.	Ammonia. Albuminoid. Suspended.	Chlorine.	Oxygen consumed.	Hardness.	Iron.
1920.											
December	.42	3.97	1.27	.0019	.0115	.0106	.0009	.17	-	1.0	.012
1921.											
January	.28	3.90	1.50	.0028	.0093	.0083	.0010	.20	-	1.0	.010
February	.17	3.10	1.15	.0004	.0070	.0058	.0012	.18	-	1.0	.012
March	.25	3.32	1.30	.0008	.0095	.0084	.0011	.17	-	0.7	.015
April	.32	3.25	1.32	.0009	.0120	.0113	.0007	.16	-	1.1	.009
May	.48	3.70	1.52	.0004	.0121	.0114	.0007	.12	-	0.5	.013
June	.24	4.47	1.45	.0011	.0115	.0102	.0013	.22	-	1.2	.021
July	.71	4.80	2.02	.0007	.0244	.0167	.0077	.18	-	0.9	.024
August	.40	4.17	1.70	.0008	.0178	.0157	.0021	.20	-	1.0	.018
September	.19	4.02	1.35	.0011	.0113	.0080	.0033	.23	-	0.9	.020
October	.17	4.40	1.55	.0003	.0106	.0104	.0002	.28	-	0.7	.016
November	.22	4.17	1.52	.0003	.0091	.0082	.0009	.24	-	1.3	.014
Average	.32	3.94	1.47	.0010	.0122	.0104	.0018	.20	-	0.9	.015

Quinepoxet River.

Date.	Color.	Residue on Evaporation. Total.	Residue on Evaporation. Loss on Ignition.	Ammonia. Free.	Ammonia. Albuminoid. Total.	Ammonia. Albuminoid. Dissolved.	Ammonia. Albuminoid. Suspended.	Chlorine.	Oxygen consumed.	Hardness.	Iron.
1920.											
December	.52	3.97	1.62	.0019	.0120	.0105	.0015	.24	-	0.7	.026
1921.											
January	.34	3.72	1.45	.0020	.0118	.0103	.0015	.21	-	0.9	.020
February	.21	4.00	1.62	.0008	.0097	.0079	.0018	.27	-	1.0	.016
March	.28	3.62	1.17	.0006	.0116	.0087	.0029	.21	-	0.7	.010
April	.39	3.72	1.60	.0011	.0141	.0114	.0027	.19	-	0.8	.010
May	.51	3.35	1.47	.0003	.0132	.0109	.0023	.15	-	0.8	.012
June	.31	4.15	1.27	.0005	.0135	.0117	.0018	.34	-	0.7	.031
July	.62	4.15	1.92	.0008	.0209	.0170	.0039	.22	-	0.8	.020
August	.42	4.40	1.82	.0011	.0207	.0164	.0043	.31	-	0.8	.019
September	.31	5.65	1.82	.0003	.0179	.0148	.0031	.66	-	1.1	.037
October	.32	5.00	1.65	.0002	.0186	.0165	.0021	.68	-	0.6	.022
November	.29	5.17	1.75	.0006	.0168	.0126	.0042	.54	-	1.1	.034
Average	.38	4.24	1.60	.0009	.0151	.0124	.0027	.34	-	0.8	.021

Wachusett Reservoir.

[Parts in 100,000.]

Date.	Color.	Residue on Evaporation. Total.	Residue on Evaporation. Loss on Ignition.	Ammonia. Free.	Ammonia. Albuminoid. Total.	Ammonia. Albuminoid. Dissolved.	Ammonia. Albuminoid. Suspended.	Chlorine.	Oxygen consumed.	Hardness.	Iron.
1920.											
December	.11	3.37	1.22	.0012	.0095	.0077	.0018	.28	–	1.0	.015
1921.											
January	.12	3.50	1.42	.0020	.0095	.0080	.0015	.23	–	0.9	.017
February	.13	3.72	1.40	.0015	.0094	.0080	.0014	.22	–	1.2	.008
March	.13	3.75	1.37	.0014	.0104	.0092	.0012	.25	–	1.2	.010
April	.16	3.47	1.42	.0006	.0104	.0095	.0009	.20	–	1.2	.008
May	.15	3.17	1.22	.0005	.0085	.0063	.0022	.20	–	0.7	.007
June	.17	3.52	1.57	.0010	.0097	.0087	.0010	.16	–	0.8	.020
July	.11	3.80	1.40	.0018	.0141	.0120	.0021	.20	–	0.7	.005
August	.12	3.02	1.25	.0004	.0119	.0111	.0008	.26	–	1.0	.007
September	.12	3.12	1.12	.0005	.0092	.0089	.0003	.23	–	1.1	.010
October	.11	3.50	1.12	.0006	.0098	.0076	.0022	.17	–	0.8	.017
November	.11	3.40	1.30	.0015	.0096	.0084	.0012	.18	–	1.1	.013
Average	.13	3.45	1.32	.0011	.0102	.0088	.0014	.22	–	1.0	.011

Sudbury Reservoir.

Date.	Color.	Residue on Evaporation. Total.	Residue on Evaporation. Loss on Ignition.	Ammonia. Free.	Ammonia. Albuminoid. Total.	Ammonia. Albuminoid. Dissolved.	Ammonia. Albuminoid. Suspended.	Chlorine.	Oxygen consumed.	Hardness.	Iron.
1920.											
December	.10	3.20	1.05	.0006	.0102	.0090	.0012	.29	–	1.1	.010
1921.											
January	.16	4.15	1.60	.0018	.0120	.0102	.0018	.30	–	1.4	.020
February	.15	4.25	1.55	.0008	.0096	.0080	.0016	.29	–	1.4	.015
March	.15	3.65	1.65	.0006	.0094	.0076	.0018	.25	–	1.6	.010
April	.17	3.70	1.25	.0010	.0142	.0118	.0024	.20	–	1.7	.008
May	.16	4.70	2.10	.0006	.0116	.0104	.0012	.20	–	1.7	.010
June	.19	3.95	1.65	.0018	.0184	.0134	.0050	.26	–	1.3	.035
July	.13	5.10	2.15	.0030	.0112	.0096	.0016	.26	–	1.1	.005
August	.16	4.20	1.85	.0014	.0134	.0110	.0024	.27	–	1.1	.015
September	.11	3.75	1.50	.0010	.0144	.0124	.0020	.22	–	1.7	.012
October	.12	3.95	1.60	.0020	.0140	.0112	.0028	.28	–	1.0	.022
November	.10	3.70	1.55	.0008	.0114	.0092	.0022	.20	–	1.1	.015
Average	.14	4.03	1.63	.0013	.0125	.0103	.0022	.25	–	1.4	.015

Framingham Reservoir No. 3.

[Parts in 100,000.]

Date.	Color.	Residue on Evaporation.		Ammonia.				Chlorine.	Oxygen consumed.	Hardness.	Iron.
					Albuminoid.						
		Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.				
1920.											
December . .	.12	4.90	1.70	.0026	.0114	.0110	.0004	.31	–	1.0	.012
1921.											
January . .	.15	4.00	1.70	.0012	.0122	.0102	.0020	.28	–	1.6	.015
February . .	.12	3.00	1.20	.0006	.0092	.0080	.0012	.22	–	1.7	.015
March . . .	.13	3.50	1.45	.0014	.0116	.0102	.0014	.26	–	1.3	.020
April . . .	.15	3.80	1.80	.0018	.0162	.0120	.0042	.20	–	1.0	.008
May . . .	.20	4.15	1.50	.0010	.0122	.0106	.0016	.24	–	1.4	.008
June . . .	.17	4.00	1.00	.0010	.0120	.0114	.0006	.22	–	1.6	.015
July . . .	.15	3.20	1.35	.0026	.0148	.0130	.0018	.26	–	1.1	.005
August . .	.19	3.90	1.00	.0020	.0142	.0124	.0018	.24	–	1.4	.005
September . .	.12	4.25	1.60	.0018	.0122	.0112	.0010	.30	–	1.6	.012
November . .	.10	4.65	2.00	.0014	.0100	.0090	.0010	.20	–	1.4	.015
Average .	.15	3.94	1.48	.0016	.0124	.0108	.0016	.25	–	1.4	.012

Ashland Reservoir.

Date.	Color.	Residue Total.	Loss on Ignition.	Ammonia Free.	Albuminoid Total.	Dissolved.	Suspended.	Chlorine.	Oxygen consumed.	Hardness.	Iron.
1920.											
December . .	.39	3.55	1.50	.0010	.0144	.0124	.0020	.30	–	1.0	.012
1921.											
January . .	.45	4.80	2.55	.0030	.0148	.0124	.0024	.29	–	1.6	.028
February . .	.47	5.10	2.20	.0010	.0116	.0098	.0018	.20	–	1.8	.030
March . . .	.45	5.20	2.25	.0026	.0142	.0132	.0010	.30	–	1.4	.020
April . . .	.41	4.30	1.50	.0014	.0182	.0164	.0018	.27	–	1.8	.015
May . . .	.52	4.55	1.40	.0012	.0144	.0124	.0020	.24	–	1.1	.020
June . . .	.72	4.30	1.90	.0020	.0170	.0128	.0042	.20	–	1.3	.030
July . . .	.70	4.45	2.20	.0014	.0212	.0186	.0026	.31	–	1.1	.025
August . .	.80	5.00	2.40	.0010	.0228	.0182	.0046	.22	–	1.0	.035
September . .	.70	4.45	1.95	.0018	.0190	.0178	.0012	.22	–	1.4	.020
October . .	.60	4.15	1.55	.0020	.0130	.0120	.0010	.25	–	1.0	.010
November . .	.56	3.75	1.15	.0016	.0176	.0170	.0006	.28	–	1.1	.040
Average .	.56	4.47	1.88	.0017	.0165	.0144	.0021	.26	–	1.3	.024

Hopkinton Reservoir.

[Parts in 100,000.]

Date.	Color.	Residue on Evaporation. Total.	Residue on Evaporation. Loss on Ignition.	Ammonia. Free.	Ammonia. Albuminoid. Total.	Ammonia. Albuminoid. Dissolved.	Ammonia. Albuminoid. Suspended.	Chlorine.	Oxygen consumed.	Hardness.	Iron.
1920.											
December . .	.34	4.70	1.80	.0008	.0084	.0084	.0000	.34	–	1.6	.045
1921.											
January . .	.50	4.00	1.65	.0036	.0140	.0116	.0024	.35	–	1.3	.040
February . .	.50	4.50	1.80	.0022	.0112	.0102	.0010	.34	–	1.4	.032
March . . .	.54	4.85	1.60	.0026	.0142	.0102	.0040	.36	–	1.6	.038
April . . .	.41	4.10	1.40	.0014	.0156	.0142	.0014	.30	–	1.4	.020
May . . .	.40	4.35	1.90	.0016	.0122	.0110	.0012	.26	–	1.3	.015
June . . .	.58	4.30	2.05	.0022	.0164	.0142	.0022	.42	–	0.8	.015
July . . .	.50	4.40	2.30	.0006	.0168	.0152	.0016	.32	–	0.6	.015
August . .	.82	4.80	2.30	.0012	.0182	.0156	.0026	.28	–	1.1	.015
September . .	.80	4.85	2.30	.0014	.0186	.0180	.0006	.30	–	1.6	.015
October . .	.55	4.50	1.90	.0004	.0146	.0114	.0032	.22	–	1.0	.025
November . .	.55	4.30	2.05	.0012	.0166	.0128	.0038	.32	–	1.3	.060
Average .	.54	4.47	1.92	.0016	.0147	.0127	.0020	.32	–	1.3	.028

Framingham Reservoir No. 2.

Date.	Color.	Residue on Evaporation. Total.	Residue on Evaporation. Loss on Ignition.	Ammonia. Free.	Ammonia. Albuminoid. Total.	Ammonia. Albuminoid. Dissolved.	Ammonia. Albuminoid. Suspended.	Chlorine.	Oxygen consumed.	Hardness.	Iron.
1920.											
December . .	.75	6.90	2.55	.0032	.0200	.0192	.0008	.52	–	1.7	.035
1921.											
January . .	.60	4.75	1.20	.0020	.0160	.0140	.0020	.44	–	1.7	.025
February . .	.51	5.85	2.80	.0006	.0132	.0110	.0022	.29	–	1.7	.030
March . . .	.45	4.40	1.90	.0014	.0134	.0100	.0034	.36	–	1.1	.032
April . . .	.70	5.90	2.20	.0042	.0242	.0180	.0062	.40	–	1.3	.035
May . . .	.51	3.70	1.50	.0030	.0192	.0164	.0028	.38	–	1.1	.040
June . . .	.90	5.80	2.40	.0026	.0190	.0172	.0018	.50	–	1.6	.040
July . . .	.90	6.95	2.60	.0090	.0236	.0210	.0026	.66	–	1.7	.070
August . .	1.28	7.85	3.10	.0114	.0284	.0258	.0026	.64	–	1.7	.080
September . .	.90	7.40	2.15	.0090	.0242	.0220	.0022	.85	–	2.2	.080
November . .	.62	8.10	2.95	.0042	.0180	.0146	.0034	1.14	–	2.3	.075
Average .	.74	6.15	2.30	.0046	.0199	.0172	.0027	.56	–	1.6	.049

Lake Cochituate.

[Parts in 100,000.]

Date.	Color.	Residue on Evaporation.		Ammonia.				Chlorine.	Oxygen consumed.	Hardness.	Iron.
					Albuminoid.						
		Total.	Loss on Ignition.	Free.	Total.	Dissolved.	Suspended.				
1920.											
December	.10	6.30	2.15	.0022	.0204	.0112	.0092	.60	–	2.2	.015
1921.											
January	.14	6.60	2.90	.0030	.0202	.0184	.0018	.56	–	2.5	.015
February	.15	6.55	1.85	.0006	.0154	.0100	.0054	.56	–	2.3	.018
March	.15	7.20	3.10	.0026	.0166	.0142	.0024	.64	–	2.3	.030
April	.15	7.45	2.20	.0010	.0242	.0158	.0084	.56	–	2.6	.010
May	.10	6.65	2.40	.0016	.0184	.0122	.0062	.52	–	2.7	.010
June	.15	7.05	2.05	.0002	.0176	.0160	.0016	.60	–	2.5	.025
July	.13	6.95	2.25	.0002	.0192	.0148	.0044	.64	–	1.8	.010
August	.15	6.60	2.25	.0020	.0176	.0174	.0002	.58	–	2.9	.005
September	.13	6.25	2.10	.0016	.0126	.0106	.0020	.54	–	3.0	.005
October	.10	7.00	2.50	.0006	.0242	.0142	.0100	.56	–	2.5	.015
Average	.13	6.78	2.34	.0014	.0188	.0141	.0047	.58	–	2.5	.014
Weston Reservoir.											
Average for the year 1921	.12	4.19	1.57	.0011	.0118	.0098	.0020	.26	–	1.2	.013
Chestnut Hill Reservoir.											
Average for the year 1921	.14	3.94	1.56	.0012	.0114	.0096	.0018	.28	–	1.4	.015
Spot Pond.											
Average for the year 1921	.08	3.67	1.41	.0012	.0131	.0110	.0021	.30	–	1.3	.012
Tap in Revere.											
Average for the year 1921	.06	3.85	1.38	.0006	.0103	.0092	.0011	.29	–	1.4	.015

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